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MHD RETROFIT STUDY

MILESTONE #8

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MHD RETROFIT STUDY

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June 14, 1983 83MSE-076

Mr. Robert J. Robinson
Deputy Director
Department of Natural Resources and Conservation
32 South Ewing Street
Helena, Montana 59620

Subject: Engineering Assessment - MHD Retrofit Study

Reference: Agreement Between DNRC and MSE, November 1, 1982

Dear Mr. Robinson:

Submitted herewith is Milestone #8, "Draft Engineering Assessment", for the Engineering Assessment of an Advanced Test System MHD retrofit to the J.E. Corette plant in Billings, Montana.

Attachment #1 represents the draft Engineering Assessment Report for implementing an Advanced Test System MHD retrofit to the Corette facility.

A statement from the Edison Electric Institute (EEI) MHD Task Force concerning the Engineering Assessment is presented in Attachment #2.

The efforts to complete Milestone #8 are summarized in Attachment #3 and constitute an invoice for activities through June 10, 1983.

If you have any questions, need additional information, or require any clarification, please let me know.

Sincerely,

JMSherick

J. M. Sherick
President

GA/JMS/lc

Attachments:
1) Draft Engineering Assessment
2) EEI Statement
3) Invoice, Milestone #8
4) Estimate, Milestone #9
5) Milestone Schedule and Status Report

ATTACHMENT #1

DRAFT ENGINEERING ASSESMENT

MOUNTAIN STATES ENERGY, INC.
P.O. BOX 3662
BUTTE, MONTANA 59702

ENGINEERING ASSESSMENT OF AN MHD ADVANCED TEST SYSTEM

JUNE, 1983

PREPARED FOR

MONTANA DEPARTMENT OF NATURAL
RESOURCES AND CONSERVATION
32 SOUTH EWING
HELENA, MONTANA 59602

NOTICE

This report was prepared as an account of work sponsored by the Department of Natural Resources and Conservation (DNRC) of the State of Montana. Neither the State of Montana nor the DNRC nor any of their contractors, subcontractors or their employees makes any warranty, express or implied or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights. Commercial products, their manufacturer or their supplies implied or referred to does not constitute approval or disapproval of the product or process by Mountain States Energy, Inc., the Department of Natural Resources and Conservation or the State of Montana.

ACKNOWLEDGEMENT

This Engineering Assessment of a potential MHD retrofit to Montana Power Company's J. E. Corette Generating Station in Billings, Montana could not have been accomplished without the review, comments and data provided by the following firms and individuals.

- Department of Natural Resources and Conservation, State of Montana
- Montana Power Company
- Iowa Public Service Co.
- Central Nebraska Public Power and Irrigation District
- Montana-Dakota Utilities
- Northern Indiana Public Service Company
- Nebraska Public Service District
- Lakeland Electric and Water
- Savannah Electric and Power Company
- Gulf States Utilities Company
- Allegheny Power System
- Public Service Company of New Mexico
- Commonwealth Edison Company
- Puget Sound Power and Light Company
- Duke Power Company
- Illinois Power Company
- Virginia Electric and Power Company
- Southern California Edison Company
- Central Illinois Light Company
- Pennsylvania Power and Light Company
- Florida Power and Light Company
- Pacific Gas and Electric Company
- Arizona Public Service Company
- Gilbert Commonwealth Inc.
- University of Tennessee Space Institute
- AVCO Everett Research Laboratories, Inc.
- Charles T. Main Inc.
- Stone and Webster Engineering Corporation
- Babcock and Wilcox Inc.
- General Electric Company
- Dr. Roy Johnson
- Dr. Don Rudberg
- Dr. Dick Rosa
- Dr. Stewart Way

ABSTRACT

Mountain States Energy, Inc. under contract with the Department of Natural Resources and Conservation of the State of Montana has conducted an Engineering Assessment for the potential MHD Retrofit of an Advanced Test System to the Montana Power Company's J. E. Corette Plant in Billings, Montana. The objective of the study was to assess the feasibility of providing an MHD retrofit to an existing power generation facility. The results of this assessment show that their were no site related conditions that would preclude a retrofit to the Corette facility.

TABLE OF CONTENTS

Page

1.0 CONFIGURATION ANALYSIS 1-1

1.1 Power Train Analysis. 1-5

1.2 HRSR Preliminary Design and Analysis. 1-9

1.2.1 Design Philosophy and Physical Description . . . 1-9

2.0 DESIGN REQUIREMENTS. 2-1

2.1 MHD System. 2-1

2.1.1 Coal-Fired Combustor and Nozzle. 2-1

2.1.2 MHD Generator. 2-2

2.1.3 Diffuser 2-2

2.1.4 Superconducting Magnet System. 2-3

2.1.5 Heat Recovery, Seed Recovery System. 2-17

2.1.6 Inverter 2-20

2.1.7 Instrumentation and Control. 2-23

2.1.8 Data Acquisition 2-30

2.2 MHD Interface Systems 2-34

2.2.1 Coal Preparation and Feed. 2-34

2.2.2 Seed 2-40

2.2.3 Oxidant. 2-45

2.2.4 Effluent Handling. 2-52

2.2.5 Auxiliaries. 2-53

Page

2.2.6 Particulate Control. 2-71

2.2.7 Substation and Transmission. 2-72

2.3 Utility Interfaces. 2-76

2.3.1 Steam. 2-76

2.3.2 Feedwater. 2-78

2.3.3 Water Systems. 2-83

2.3.4 Fuels. 2-84

2.3.5 Instrumentation and Control. 2-87

2.3.6 Electrical 2-88

2.3.7 Buildings and Structures 2-88

2.4 Site. 2-92

2.4.1 MHD Systems. 2-92

2.4.2 Interface Systems. 2-93

2.4.3 Liquid Waste Storage and Disposal. 2-96

2.4.4 Solid Waste Storage and Disposal 2-98

2.4.5 Transportation 2-98

2.4.6 Land, Building, Structures, & Area Requirements. 2-100

2.5 Modifications 2-107

2.5.1 Steam and Feedwater. 2-107

2.5.2 Water Systems. 2-108

2.5.3 Fuels. 2-109

Page

2.5.4 Effluent 2-109
2.5.5 Control Instrumentation. 2-110
2.5.6 Electrical Systems 2-110
2.5.7 Site 2-111

2.6 Operational 2-112
2.6.1 MHD Systems. 2-112
2.6.2 Support Systems. 2-113
2.6.3 Interface Systems. 2-115
2.6.4 System Integration 2-116
2.6.5 Special Conditions 2-116

3.0 ENVIRONMENTAL REQUIREMENTS 3-1
3.1 Siting Requirements/NEPA-MEPA 3-1
3.1.1 Montana Regulations. 3-1
3.1.2 Federal Regulations. 3-7

3.2 Air Quality 3-8
3.2.1 New Source Performance Standards 3-8
3.2.2 Ambient Air Quality Standards. 3-13
3.2.3 Prevention of Significant Deterioration (PSD). . . . 3-16

Page

3.3 Water Quality 3-19
    3.3.1 Montana Regulations. 3-19
    3.3.2 Federal Regulations. 3-24

3.4 Solid Waste 3-26
    3.4.1 Montana Regulations. 3-26
    3.4.2 Federal Regulations. 3-30

3.5 Other Applicable Requirements 3-30
    3.5.1 Local Regulations. 3-30
    3.5.2 State Regulations. 3-33
    3.5.3 Federal Regulations. 3-33

3.6 Health and Safety 3-34
    3.6.1 Construction 3-35
    3.6.2 Operation. 3-35

3.7 Summary of Environmental Requirements 3-36
    3.7.1 Siting Requirements/NEPA-MEPA. 3-36
    3.7.2 Air Quality. 3-37
    3.7.3 Water Quality. 3-37
    3.7.4 Solid Waste. 3-38
    3.7.5 Safety and Health. 3-38
    3.7.6 Montana Department of Natural Resources
        and Conservation Response 3-38

Page

4.0 SOCIOECONOMIC CONSIDERATIONS 4-1
4.1 MMFSA, MEPA, NEPA 4-2

4.2 Montana Antiquities Act Permit. 4-4
4.2.1 Federal Ownership. 4-4
4.2.2 Private Ownership. 4-5
4.2.3 Situations Involving Montana State-Owned Lands 4-5

4.3 Land Use and Zoning Requirements. 4-6
4.3.1 Private Ownership. 4-6
4.3.2 Federal Ownership. 4-7

5.0 COST ESTIMATE. 5-1
5.1 Supportive Definitions. 5-1
5.2 Cost Estimates. 5-5
5.3 Confidence Level. 5-9

6.0 PROJECT SCHEDULE 6-1

7.0 PROGRAM IMPLEMENTATION 7-1

8.0 TOPICS FOR FURTHER STUDY 8-1
8.1 Initial Discussion. 8-1
8.2 Study Topics. 8-2

BIBLIOGRAPHY. B-1

LIST OF FIGURES

		Page
Figure 1-1	Corette ATS Schematic	1-13
Figure 1-2	Supersonic Generator Performance Map	1-14
Figure 1-3	Subsonic Generator Performance Map	1-15
Figure 1-4	Corette HRSR Boiler Profile	1-19
Figure 2-1	Superconducting Magnet Dimensional Schematic	2-5
Figure 2-2	Curve of On-Axis Field Versus Distance Along Axis	2-7
Figure 2-3	Helium Refrigeration System	2-13
Figure 2-4	Corette ATS Inverter Schematic One-Line Diagram	2-21
Figure 2-5	Control System Overview	2-25
Figure 2-6	Coal Preparation and Feed System	2-37
Figure 2-7	Seed	2-42
Figure 2-8	Oxidant Supply and Air Separation	2-47
Figure 2-9	Oxidant Supply System - Typical Plant (Air Products)	2-49
Figure 2-10	Oxidant Supply System - Typical Plant (Lotepro)	2-50
Figure 2-11	Ash and Seed/Waste Recycle Streams	2-54
Figure 2-12	Feedwater	2-57
Figure 2-13	Channel Cooling Water	2-58
Figure 2-14	Inverter Cooling Water	2-60
Figure 2-15	Service Water	2-62
Figure 2-16	Bearing Cooling Water	2-63
Figure 2-17	Potable Water	2-65
Figure 2-18	Fire Protection	2-66
Figure 2-19	Natural Gas	2-68

Figure 2-20 Service and Instrument Air 2-70
Figure 2-21 Substation and Transmission 2-74
Figure 2-22 Steam 2-79
Figure 2-23 Feedwater 2-82
Figure 2-24 Billings Steam Plant Plan View 2-90
Figure 2-25 Corette Plant MHD Plan View 2-91
Figure 2-26 Liquid Waste 2-97
Figure 2-27 Solid Waste 2-99
Figure 3.1 MMFSA, MEPA, and NEPA Process for Federal or Private MHD Retrofit in Montana 3-3
Figure 3.2 NEPA Process in States Other Than Montana For Privately Owned Retrofit 3-9
Figure 3.3 Air Quality Permitting Process 3-20
Figure 3.4 Process Diagram for Application of MPDES and NSPS Regulations for Water for an MHD Retrofit of an Existing Power Plant in Montana 3-22
Figure 3.5 Process Diagrams for 404 Permit, Turbidity Exemptions, and Water Appropriate Regulations in Montana Applicable to an MHD Retrofit 3-25
Figure 3.6 Application of Solid Waste Disposal Regulations to an MHD Retrofit of Power Plants in Montana 3-27
Figure 6-1 MHD Retrofit Long Range Plan 6-4
Figure 7-1 Interface of Recommended National Program with ATS Retrofit 7-9

LIST OF TABLES

Page

Table 1-1 Summary of Plant Performance 1-10

Table 1-2 Summary of Power Train Specifications 1-11

Table 1-3 Channel Geometry and Magnetic Field Strength 1-12

Table 2-1 Magnet Design Characteristics 2-6

Table 2-2 Magnet System Utility Requirements 2-9

Table 2-3 Boiler Stop Valve Steam Conditions for Corette Boiler and HRSR 2-19

Table 2-4 MHD Process Control Requirements 2-27

Table 2-5 Points Monitored by Data Acquisition Computer 2-32

Table 2-6 Montana Rosebud Subbituminous Coal 2-35

Table 2-7 Coal Storage and Predrying Equipment 2-38

Table 2-8 Seed Handling Equipment Capacities and Flow Requirements 2-43

Table 2-9 Boiler Stop Valve Steam and Feedwater Conditions 2-80

Table 2-10 Water Usage 2-85

Table 3-1 Major Environmental Laws Governing an MHD Retrofit of an Existing Power Plant in Montana 3-2

Table 3-2 New Source Performance Standards (Air) for Electric Utility Steam Generating Units (44FR 33580) 3-11

Table 3-3 National Ambient Air Quality Standards 3-14

Table 3-4 Montana Ambient Air Quality Standards 3-15

Table 3-5 Prevention of Significant Deterioration in Air Quality: Allowable Increments 3-17

Table 5-1 Estimated Construction Costs for Oxygen Enriched 250 MW_t MHD Retrofit to Corette Power Plant 5-10

INTRODUCTION AND SUMMARY

BACKGROUND

The Montana State Legislature Appropriated $500,000 in 1979 to enhance the prospects for state of Montana participation in the recognized benefits to be obtained from commercialization of Magnetohydrodynamics (MHD) technology.

The Montana Power Company and Mountain States Energy, Inc., following this legislative mandate, proposed a two phase program to define performance requirements and to develop an Engineering Assessment of an MHD retrofit to an existing Montana power plant which will serve as a next-generation Advanced Test System (ATS). As conceived, this MHD retrofit Advanced Test System will provide the decisive, experimental, cost and performance basis required for the utility industry to confidently proceed with the first commercial MHD generating unit.

Phase I of the State of Montana sponsored project led to the definition of performance requirements, formulated from the utility industry perspective, for the Advanced Test System to assure that the concerns of the ultimate user of this technology are taken into account in the design of the Advanced Test System. The Montana Power Company, as an independent contractor to the State of Montana, led the Edison Electric Institute MHD Task Force in the development of these utility industry performance requirements.

In Phase II, an engineering analysis of the Advanced Test System was performed expanding the performance requirements established in Phase I into functional, operational and design requirements to be used in the development of a conceptual design for an MHD Advanced Test System.

The results of the Phase II engineering assessment are documented in this report and consist of the following major elements.

1. Selection of a power plant for analysis located in the state of Montana and representative of plants considered candidates for MHD retrofit by the utility industry.

2. Specification of a baseline MHD retrofit configuration for the selected plant.

3. Thermodynamic analysis of the baseline configuration including development of heat and mass balances, and predictions of both MHD power train and bottoming plant performance.

4. Development of functional, operational and design requirements for the selected retrofit configuration.

5. Estimation of preliminary costs and schedules for design and construction of the selected MHD retrofit Advanced Test System.

6. Formulation of modifications to the national MHD Development Program to reflect an MHD retrofit concept as an Advanced Test System (ATS).

SELECTION OF A REPRESENTATIVE MONTANA POWER PLANT

According to the guidelines provided by the State of Montana, the engineering assessment should be performed for a power plant within the state of Montana.

In order for the study to have the broadest possible support from the utility industry, the Montana plant so chosen should be representative of plants the utility industry considers candidates for MHD retrofit.

Consequently, 213 utilities nationwide were requested to participate in the program by first submitting plants they considered most amenable to MHD retrofit, within prescribed guidelines, to form the basis for selection of a Montana plant for analysis, and second by providing a technical critique of the analysis from the utility perspective.

Seven plants, representing a broad geographical cross section of utilities, were subsequently submitted as potential candidates. Included among these responses were three Montana power plants from which the plant to be analyzed was ultimately selected.

Table 1 summarizes the significant parameters of the plants submitted by the utility industry as candidates for MHD retrofit, including the plants located within the state of Montana.

Two of the plants, the Frank Bird and the Lewis and Clark plants, submitted by the Montana Power Company and Montana Dakota Utilities respectively, are representive of smaller, earlier-generation plants with relatively low steam

conditions and no reheat. The Lewis and Clark plant presently burns lignite which typically has very high moisture content and is not the fuel-of-choice for early MHD application.

The remaining candidates are representative of more modern utility practice with higher steam conditions and reheat.

On technical grounds it was established that any of the three Montana plants could adequately represent the essential characteristics of the candidate plants. Clearly, however, the responses obtained indicate more interest exists in the utility industry for MHD retrofit of more modern power plants of a class typified by the J.E. Corette plant located in Billings, Montana.

The J. E. Corette Plant was consequently selected for analysis as an MHD retrofit Advanced Test System based upon the preponderence of utility interest and a number of supporting secondary issues, some of which are now addressed. It is emphasized that none of these issues are decisive, but primarily support the selection based upon expressed utility interest.

Although not an essential technical criteria, selection of a plant with reheat permits a more accurate simulation of flue-gas temperature history in the MHD Heat Recovery Seed Recovery system of projected commercially attractive MHD plants. As a result ash and seed condensation mechanisms can be better represented. Consequently, the uncertainty and risk associated with extrapolating ATS experience to early commercial MHD plants is decreased if the ATS employs reheat.

Since the Corette turbine-generator is presently boiler-limited because of air quality considerations, an operational advantage for the choice of this plant as the subject of the ATS engineering analysis is the ability to operate the Corette turbine at design conditions with additional steam from the MHD boiler.

The remainder of this report is dedicated to an engineering analysis of the Montana Power Company's J. E. Corette plant as an MHD retrofit Advanced Test System.

SELECTION OF FLOW PROCESS CONFIGURATION

Prior to selecting the configuration for the retrofit flow processes and, consequently, choosing the interfaces between the J. E. Corette plant and the MHD Advanced Test System, the size or scale (i.e., thermal input power) of the MHD components must be determined. The rational determination of the MHD retrofit input power must be based upon the risk and uncertainty introduced into the predicted performance and cost of both the MHD Advanced Test System and the first commercial plant as a result of the choice of ATS size. Implicit in the determination of an appropriate ATS scale is the additional assumption that the ATS will be the only intermediate step between present technology and the first commercial MHD power plant.

Assuming moderate technical risk and uncertainty is acceptable in scaling expected ATS performance from the most feasible, largest scale engineering development program (i.e., 50 MW_t thermal input power) the ATS size should not be substantially larger than 250 MW_t. By implication a factor

of 5 in scaling from engineering development to the ATS MHD retrofit characterizes moderate risk and uncertainty as developed more fully in section 7.0.

The capital cost associated with an MHD retrofit ATS also tends to limit the size of the ATS MHD retrofit components to the 250 MW_t range.

The upper limit of an ATS MHD retrofit size has been established based upon cost of components and uncertainty in extrapolating ATS design information from the 50 MW_t development tests.

The lower limit for the Advanced Test System scale is determined from the cost and technical risk and uncertainity inherent in basing the first commercial MHD design upon the experimental results to be obtained from the ATS. The controlling uncertainties for this extrapolation are those acceptable by the utility industry - the principle source of funds for commercial MHD power plants.

The range of risks associated with scaling new thermal generation technology from demonstration scale to commercial prototype was addressed by the Edison Electric Institute MHD Task Force as a part of the previously mentioned Phase I study.

An analysis of those results indicate that utilities generally associate a relatively low risk with extrapolation up to a factor of 1.5, a relatively moderate risk with extrapolation up to factor of 3 and increasing high risk with extrapolation greater than a factor of 3.

It is assumed that the utility, or perhaps consortium of utilities, that will ultimately utilize ATS results to provide the basis for commercial MHD design would limit their risk exposure to the moderate range. Consequently, extrapolation from ATS to a first commercial plant by a factor greater than about 2 or 3 is not considered viable.

Recent overall MHD commercial plant studies employing the best present-day cost and performance analyses indicate that the break-even scale for the first commercial plant is probably in the 500 MW_t range with an uncertainty of up to at least 1000 MW_t based upon the present state of the technology.

Assuming optimistically that the first commercial plant will be near the lower limit of this range (500 to 750 MW_t) and that the developers of the first commercial unit will accept no more than moderate uncertainty (factor of 2 or 3 in scaling), then the minimum size of the ATS is also fixed in the 250 MW_t range.

The rationale for selecting 250 MW_t thermal input power for the Advanced Test System MHD retrofit, based upon scaling requirements both to the first commercial MHD generating unit and from the supporting engineering development program, is thus established.

Comparing the thermal input of the ATS (250 MW_t) with the thermal input of the Corette Plant (460 MW_t) indicates that the retrofit will only be capable of providing about one-half of the steam required to power the Corette turbine-generator. Consequently, a full turbine retrofit (MHD Heat Recovery/Seed Recovery (HRSR) unit providing all turbine steam) is not

feasible as a result of the above self-imposed constraints on scale. Therefore a partial turbine retrofit (HRSR unit providing only part of the steam to the turbine) with a resulting steam connection between the retrofit and the Corette plant is proposed.

Consequently, the MHD retrofit ATS that has been evolved features parallel steam flow from two boilers powering the existing Corette turbine-generator.

Principle MHD retrofit and existing Corette flow process interfaces thus occur in the feedwater, superheat steam and reheat steam flows.

The retrofit configuration selected for analysis as an Advanced Test System is illustrated in Figure 1-1. Although this configuration does not utilize low grade heat with maximum efficiency, it does provide for both a simple interface with and minimum pertubations to the existing Corette facility. This configuration is believed to represent one of the best methods for interfacing an MHD retrofit with an existing power plant for the purpose of providing a test system.

Operation and control of two dissimilar boilers, implied by this configuration, although not unprecedented, is an issue requiring further careful analysis and design beyond the treatment herein.

SUMMARY

The following elements of this engineering assessment are considered in detail in the remainder of this document.

1. Configuration Analysis: The basic plant flow process configuration evolved in this section is subjected to a detailed thermodynamic heat and mass balance in order to develop the performance requirements of each component of the retrofit. Variations of the basic configuration were also examined and resulting recommendations for the Conceptual Design Phase following this Environmental Assessment are presented.

2. Design Requirements: Following determination of component performance requirements, the detailed design requirements for components, subsystems, and systems are developed and presented. Engineering, environmental, and socioeconomic requirements are addressed.

3. Cost and Schedule: Preliminary costs and schedules are developed for design, fabrication, and construction of the proposed Advanced Test System MHD Retrofit. The costs and schedules associated with the supporting Engineering Development Program are not considered here.

   The results indicate that the proposed 250 MW_t ATS can be operational in the early 1990's at an estimated cost of up to $250 million (1983 dollars).

4. Program Implementation: An engineering development program based upon the assumption of moderate technical and cost risk and uncertainty is proposed to support the MHD Retrofit program by providing the experimental basis for ATS component design. The costs and schedules for this development program are not considered in detail; however, an examination of the interfaces between the ATS MHD Retrofit program and the engineering development program indicate that the development program, particularly for the Heat Recovery Seed Recovery System will probably determine the critical schedule path to implementation.

5. Topics for Further Study: A number of unresolved issues and options were developed during the course of this Engineering Assessment. Further in-depth analysis beyond the scope of the present study is recommended for final resolution prior to or in conjunction with the follow-on design phase of the ATS.

Name of Plant	Lewis & Clark	Frank Bird	J. E. Corette	Sheldon Unit #2	Canaday	Geo. Neal Unit #1	D. H. Mitchell, #11
Location	Sidney, MT	Billings, MT	Billings, MT	Hallam, NE	Lexington, NE	Sioux City, IA	Gary, Ind.
Utility Company	MDU	MPC	MPC	NPPD	CNPP & ID	Iowa Pub. Svc. Co.	No. Ind. P. S. C.
Power Output, MW_e (net, max)	51	66	163	123	96	132	110
Fuel	Lignite	#2 Fuel Oil	Rosebud Coal	Sub-bit. Coal	#6 Fuel Oil	Coal or Nat. Gas	Coal
Thermal Input, (10^8 BTU/Hr.)	5.75	7.71	16.34	12.5	9.00	12.5	11.07
Plant Heat Rate, BTU/KW-Hr.	11270	11840	9843	10160	9375	9470	10075
Overall Efficiency, pct	30.3	28.8	34.8	33.6	34.6	36.0	33.9
Turbine:							
Number of Stages	16	20	22	20	23	21	--
Feedwater Heaters	5	4	6	5	5	6	5
Turbine Reheat	NO	NO	YES	YES	YES	YES	YES
Inlet Steam Flow, lbm/hr	475,000	590,000	1.23×10^6	830,000	651,000	948,600	783,000
Inlet Steam Pressure, psia	1264	863	1903	1864	1814	1815	1815
Inlet Steam Temperature, deg. F	950	900	1000	1000	1000	1000	1000
Inlet Steam Enthalpy, BTU/lbm	1468	1453	1478	1479	1480	1480	1480

DATA SUMMARY OF RETROFIT CANDIDATES

TABLE 1

1.0 CONFIGURATION ANALYSIS

The purpose of the configuration analysis was to develop a retrofit design configuration that would be compatible with the Corette plant and would assure that the objectives of the ATS demonstration plant could be achieved. According to Reference 2, "The main emphasis of the Advanced Test System is not to achieve performance goals expected from a commercial facility, but rather to provide sound evidence that can be used as a basis for reliable prediction that a first generation commercial power plant using the technology could be competitive with conventional electric energy generating technologies. The purpose of the Advanced Test System is to demonstrate, at an adequate scale, that all components necessary for the assembly of a commercial size plant are available."

Several important performance requirements follow as a consequence of this. These are discussed below.

1. Demonstrate that the heat recovery concepts which have been developed to date are workable. This should include demonstration of oxidant preheat and demonstration of the radiant and convective sections of the heat recovery boiler.

2. Demonstrate that all critical MHD and Heat Recovery components can be designed to meet durability and reliability requirements for long duration operation with acceptable maintenance.

3. Achieve the same or greater overall plant efficiency as the original plant, with significantly increased net power output.

In developing a preliminary design for an MHD retrofit to the Corette plant it was also necessary to take into account several constraints which are imposed by the Corette plant itself, by the present technology base for MHD, or by the nature of what one wishes to accomplish in a demonstration project such as this. These are addressed in the following discussion.

1. The scale-up of MHD components is limited by the present technology base and test experience. The largest long-duration MHD test facility in this country is the Component Development and Integration Facility (CDIF), located in Butte, Montana. It is limited to the testing of MHD components which have a thermal input power rating of 50 MW or less. Since the Corette plant is rated at about 460 MW_{th}, the required scale-up is nearly an order of magnitude over existing components, if one assumes a full turbine powering from the MHD Heat Recovery System alone. Since such a large scale-up implies a high degree of uncertainty and risk, it becomes necessary to consider an alternative approach in which some fraction of the steam is supplied from the Heat Recovery System (HRS), with the balance being supplied by firing of the Corette boiler at a reduced rate.

2. There is a constraint on the Corette boiler which is imposed by efficiency considerations. The boiler should not be operated at below 45 percent of its rated output level in order to insure a reasonable plant heat rate. This constraint was imposed only for purposes of

roughly sizing the HRSR System, and in no way precludes running the Corette boiler at below that level.

3. In order to minimize the capital expense as well as downtime due to construction, the retrofit design should impact the existing plant as little as possible, and maximum use should be made of existing plant equipment.

4. Because Corette is a base-loaded plant, the retrofit design must be compatible with this mode of operation. In particular, it should be possible to accomplish switchover from combined cycle to stand-alone steam plant operation, or vice-versa, within a few minutes. In addition, the MHD interface must not adversely affect plant performance during stand-alone steam plant operation.

The approach to the design task was to break the problem into two main parts; the MHD power train and the heat recovery system. The design point for the power train was determined by a parametric study that relied on computer models of the generator and combustor. The objective was to determine the combination of preheat and oxygen enrichment that would yield an acceptable power output. The results and the study itself are described in section 2.1.

The heat recovery system design proved to be a more difficult task than the power train analysis, primarily because there is no known software which can adequately simulate either the complex geometry or the heat transfer phenomena that occur. The results of heat recovery system design effort are summarized in Section 1.2.

One point which was considered in some detail during the HRSR design effort was the question of whether or not seed reprocessing would be an integral part of the ATS plant. The design which is recommended here is one in which the slag/seed mixture is collected at a number of points in the power train and heat recovery system, but which has no reprocessing on-site. The reasons for this are, first, that seed reprocessing is only loosely coupled to plant operation, and is, therefore, not essential to it, and secondly, that space limitations at the Corette plant would probably prohibit any on-site reprocessing plant. It is strongly recommended; however, that a pilot seed reprocessing plant be built and operated during the operating life-time of the ATS, at a scale that would provide a good basis on which to design a commercial size seed reprocessing plant. Demonstration of seed reprocessing is essential to the commercialization of MHD power generation.

Based on the power train analysis and the Heat Recovery design specifications, an overall heat and mass balance for the plant has been calculated. In some cases the flow rates, temperatures, and pressures have been estimated from past experience or previous studies of similar retrofit designs. The final heat and mass balance is shown in Figure 1-1. The results are consistent with other retrofit studies except, perhaps for the fact that the design point operation will be at a slightly higher oxygen enrichment level (36 mole pct.) than might be expected. This is due to the assumption that the Air Separation Unit could use an internal compression process as described by Juhasz[5] to reduce the power requirement of the ASU compressor. A summary of all the important design point data is shown in Table 1-1. It should be noted that the retrofit schematic, Figure 1-1, has been revised in a few places to take into account comments from reviewers.

Also, the seed processing loop has been eliminated, as noted above, and an error in flue gas circulation has been corrected. The cooling water paths have also been better defined.

1.1 Power Train Analysis

The performance of an MHD generator is dependent on a large number of design parameters which must be selected or evaluated to provide the desired performance. Selection of these parameters must also take into account cost and other constraints. Evaluation of these parameters is best accomplished using performance analysis computer codes which model the physical phenomena of the MHD process. The use of computer codes allows the variation of a large number of parameters and the use of complex equations modeling the physical process. Three codes have been used in the present analysis to model the MHD topping cycle of the retrofit system.

The combustor was analyzed using CECTRN, a NASA chemical equilibrium code which computes combustor flame temperature as well as the mole fractions of all important chemical species that are produced as combustion products. In addition, the code simulates the effects of accelerating the gas through the nozzle by predicting Mach numbers, pressures, and temperatures at the exit plane of the nozzle.

The MHD generator was analyzed using a modified form of MHDUTA, a quasi-one-dimensional generator code that was originally written at the University of Texas at Arlington. The code is capable of predicting a number of generator variables, including end-to-end Hall voltage; generator power

output; and profiles of temperature, pressure, Mach number, current density, Hall and transverse voltages, all as functions of axial distance. These two codes are described in greater detail in Appendix A.

Since the performance of the power train depends on the oxidizer preheat temperature and the amount of oxygen enrichment, a parametric study was done to determine the values of each of these variables that would yield a maximum or near-maximum net power output for the generator. The combustor thermal input was fixed at 250 MW_t and the diffuser exit pressure was set at 1.0 atmospheres. A number of different combinations of preheat temperatures and enrichment levels were simulated as described in Appendix A. The results are shown in Figures 1.1 and 1.2.

Six values of the N/O molar ratio were selected to compare in the present study. The six values are (with oxygen enrichment factor, OEF values shown in parentheses), 3.727 (0%), 3.0 (19.5%), 2.5 (32.9%), 2.0 (46.3%), 1.75 (53.1%), and 1.5 (59.8%). The first value listed, 3.727 (0%) is for air with no oxygen enrichment. Three values of oxidizer preheat were also considered, 900 K (1160°F), 1100 K (1520°F), and 1300 K (1800°F). The analysis codes were run to predict the performance of MHD topping units designed for various selected combinations of the oxygen enrichment and preheat values listed above. Figures 1-1 and 1-2 summarize the results of these runs for both subsonic and supersonic cases in the form of a performance map of MHD electrical power for variations of oxygen enrichment and preheat. The percent of total available enthalpy extraction is indicated on this map. The combustion total pressure is indicated in brackets by each point. A constraint line on the map indicates the portion of the map in which the

combinations of oxygen enrichment and preheat can be achieved in a practical design.

A comparison of Figures 1-1 and 1-2 shows that there are only marginal performance differences between the subsonic and supersonic cases. Given the uncertainties that exist in the computer analysis, these differences are probably not significant, and one can conclude that, based on the analysis results alone, subsonic and supersonic generators will give essentially the same performance for the assumed set of constraints (10 meter length and 250 MW_t input). However, other considerations have led to the choice of a supersonic channel. First, the large scale experiments to date have been supersonic designs, and consequently the operation of large supersonic channels is well understood. Secondly, there are various control problems that may arise with large scale subsonic channels. These problems can be solved, but some experimentation may be necessary to develop the optimum design and control strategy for subsonic generators. The relative uncertainty in the design and control of subsonic channels and the lack of any substantial performance benefits dictates that a supersonic generator be used for this first retrofit.

The operation of MHD topping cycles require a relatively large combustion total pressure compared to the requirements of a conventional steam power plant. A significant amount of the MHD power produced must be used for compression of the oxidizer flow to the MHD combustor. The energy requirements of an oxygen plant must also be considered if oxygen enrichment of the oxidizer is required. The net power of the MHD topping cycle for the supersonic cases is shown in Figures 1-2 and 1-3. The net power is the power

feasible as a result of the above self-imposed constraints on scale. Therefore a partial turbine retrofit (HRSR unit providing only part of the steam to the turbine) with a resulting steam connection between the retrofit and the Corette plant is proposed.

Consequently, the MHD retrofit ATS that has been evolved features parallel steam flow from two boilers powering the existing Corette turbine-generator.

Principle MHD retrofit and existing Corette flow process interfaces thus occur in the feedwater, superheat steam and reheat steam flows.

The retrofit configuration selected for analysis as an Advanced Test System is illustrated in Figure 1-1. Although this configuration does not utilize low grade heat with maximum efficiency, it does provide for both a simple interface with and minimum pertubations to the existing Corette facility. This configuration is believed to represent one of the best methods for interfacing an MHD retrofit with an existing power plant for the purpose of providing a test system.

Operation and control of two dissimilar boilers, implied by this configuration, although not unprecedented, is an issue requiring further careful analysis and design beyond the treatment herein.

valuable to future design and scale-ups of the MHD topping units to commercial sizes.

The high oxygen enrichment case with an OEF of 53.1% (N/O of 1.75) and an oxidizer preheat of 900 K was thus chosen for the present design study. All of the cases shown in Figures 2 through 4 were run for an MHD channel active length of 10 meters. Without further study, it could not be certain that the channel length of 10 meters was optimal. Holding all other design parameters fixed except the combustion pressure, a variation of the length was made. A slight increase in MHD electrical power was achieved for the longer channels, but only at the expense of substantial increases in combustor pressure. The increased oxidant compressor power would eliminate any small gains seen in the MHD electrical power. For this reason the 10 meter channel was chosen for this design.

The final specifications for the chosen channel are listed in Table 1-2. The calculated channel geometry is listed in Table 1-3.

1.2 HRSR Preliminary Design and Analysis

The following subsections describe the progress to date in the preliminary design and analysis of the heat recovery, seed recovery boiler (HRSR).

1.2.1 Design Philosophy and Physical Description

After reviewing the pertinent literature, and following consideration of more exotic designs,[12] it was decided that the best compromise for the heat

TABLE 1-1

SUMMARY OF PLANT PERFORMANCE

		Existing Plant	Retrofit Case 1
1.	Thermal Input Power:		
	MHD		250 MW
	Corette	465 MW	266.7 MW
	Total	465 MW	516.7 MW
2.	Net Elec. Power Output:		
	MHD		12.5 MW
	Corette	165 MW	165 MW
	Total	165 MW	177.5 MW
3.	Overall Plant Efficiency	35.5%	34.3%
4.	Gross MHD Power (AC)		28.4 MW
5.	Compressor Requirements:		
	Blend Oxid. Compr.	6.07 MW	6.61 MW
	ASU Compr.		6.76 MW
	Total		12.83 MW
6.	Oxidizer Flow Rates:		
	At ASU Exit		15.1 kgm/sec
	At Mixer Exit		46.1 kgm/sec
7.	Coal Flow Rates:		
	MHD		10.0 kgm/sec
	Corette	23.3 kgm/sec	13.8 kgm/sec
	Total	23.3 kgm/sec	23.8 kgm/sec
8.	Rosebud Coal:		
	HHV, MHD		24.95 MJ/kgm
	HHV, Corette	19.96 MJ/kgm	19.96 MJ/kgm
	Moist. Content MHD		5.0%
	Moist. Content - Corette	24.0%	24.0%

TABLE 1-2

SELECTED MHD CHANNEL AND TOPPING UNIT SPECIFICATIONS

Channel Type: Diagonal Wall

Channel Length: 10 meters

MHD Electrical Power: 28.7 MW

Peak Magnetic Field Strength: 4.5 T

Combustor: 250 MW Fuel Thermal Input
Heat Loss, 5% of Thermal Input
Slag Rejection, 70%
Combustion Pressure 5.85 atm.

Fuel: Montana Rosebud Coal, Dried to 5% H_2O
Mass flow rate, 10.01 kg/s (12.77 kg/s as rec'd.)

Oxidizer: Oxygen Enriched Air, OEF 53.1%, (N/O 1.75)
Mass Flow Rate, 46.16 kg/s
Preheat Temperature, 900 K
Air Separation Unit Mass Flow Rate, 14.92 kg/s
Air Separation Unit Oxygen Content, 71.85 mass pct.
Blend Air Mass Flow Rate, 31.24 kg/s

Seed: 1% k by weight using K_2CO_3
Mass Flow Rate of K_2CO_3, 0.992 kg/s

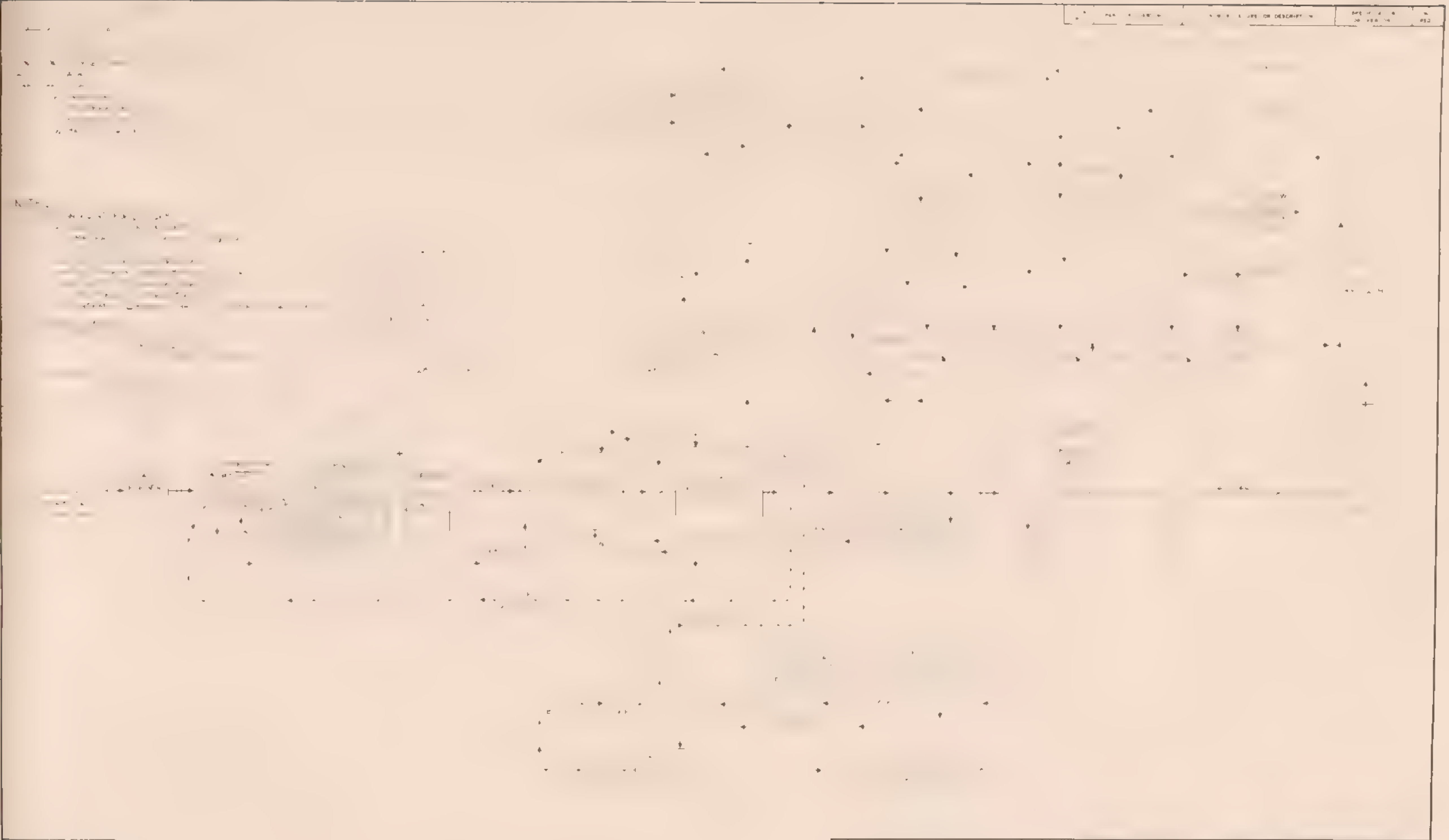
TABLE 1-3

CHANNEL GEOMETRY AND MAGNET FIELD STRENGTH
250 MW THERMAL, 53.1% OXYGEN ENRICHMENT, 900 K OXIDIZER PREHEAT

X(m)	Area (M^2)	Width (M)	Height (M)	B (Telsa)
0.0	1.455D-01	3.814E-01	3.814E-01	4.500E-01
5.000D-01	1.540D-01	3.920E-01	3.928E-01	4.500E+00
1.000D+00	1.678D-01	4.085E-01	4.108E-01	4.500E+00
1.500D+00	1.828D-0-1	4.256E-01	4.295E-01	4.500E+00
2.000D+00	1.990D-01	4.434E-01	4.489E-01	4.500E+00
2.500D+00	2.166D-01	4.618E-01	4.691E-01	4.500E+00
3.000D+00	2.357D-01	4.809E-01	4.901E-01	4.500E+00
3.500D+00	2.563D-01	5.007E-01	5.119E-01	4.500E+00
4.000D+00	2.782D-01	5.209E-01	5.342E-01	4.500E+00
4.500D+00	3.014D-01	5.414E-01	5.567E-01	4.500E+00
5.000D+00	3.258D-01	5.621E-01	5.796E-01	4.500E+00
5.500D+00	3.514D-01	5.830E-01	6.027E-01	4.500E+00
6.000D+00	3.782D-01	6.041E-01	6.262E-01	4.500E+00
6.500D+00	4.061D-01	6.252E-01	6.496E-01	4.500E+00
7.000D+00	4.349D-01	6.462E-01	6.730E-01	4.500E+00
7.500D+00	4.645D-01	6.672E-01	6.962E-01	4.500E+00
8.000D+00	4.947D-01	6.879E-01	7.192E-01	4.500E+00
8.500D+00	5.253D-01	7.082E-01	7.418E-01	4.500E+00
9.000D+00	5.570D-01	7.285E-01	7.645E-01	4.500E+00
9.500D+00	5.892D-01	7.486E-01	7.871E-01	4.500E+00
1.000D+01	6.170D-01	7.655E-01	8.059E-01	4.500E-01

FIGURE 1-1

CORETTE ATS RETROFIT SCHEMATIC



LTR	DESCRIPTION	DATE	APPROVED

REVISIONS

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES ON
FRAC DEC ANG

MATERIAL

SURFACE FINISH
AS NOTED

APPROVALS	DATE
DRAWN BY	
CHECKED BY	
DESIGNED BY	
PROJ ENGR	
ENGR MGR	

U.S. DEPARTMENT OF ENERGY
COMPONENT DEVELOPMENT & INTEGRATION FACILITY
BUTTE PROJECT OFFICE BUTTE, MONTANA

MOUNTAIN STATES ENERGY INC
P.O. BOX 3767
BUTTE, MONTANA
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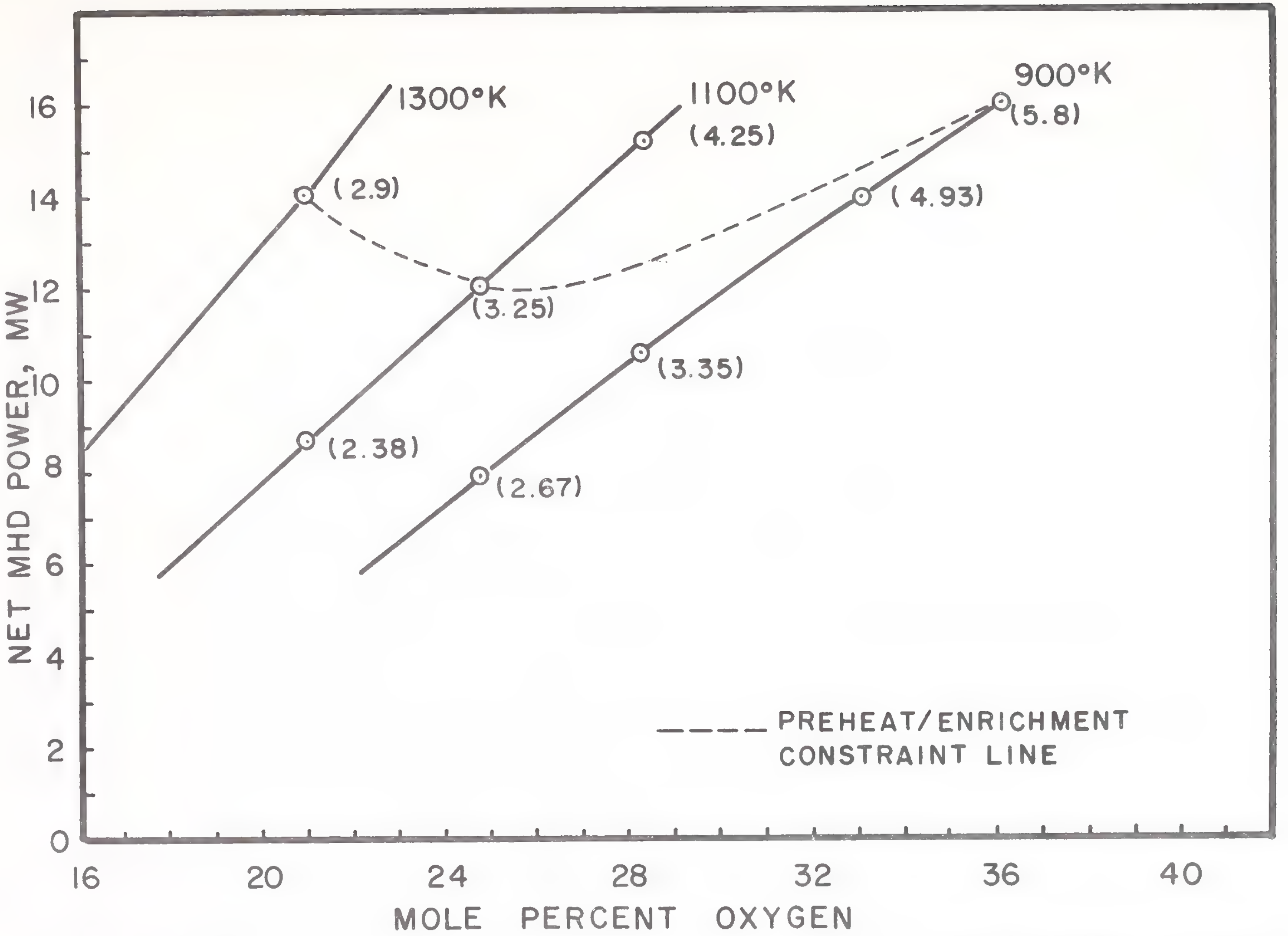


FIG. 1-2: SUPERSONIC GENERATOR PERFORMANCE MAP

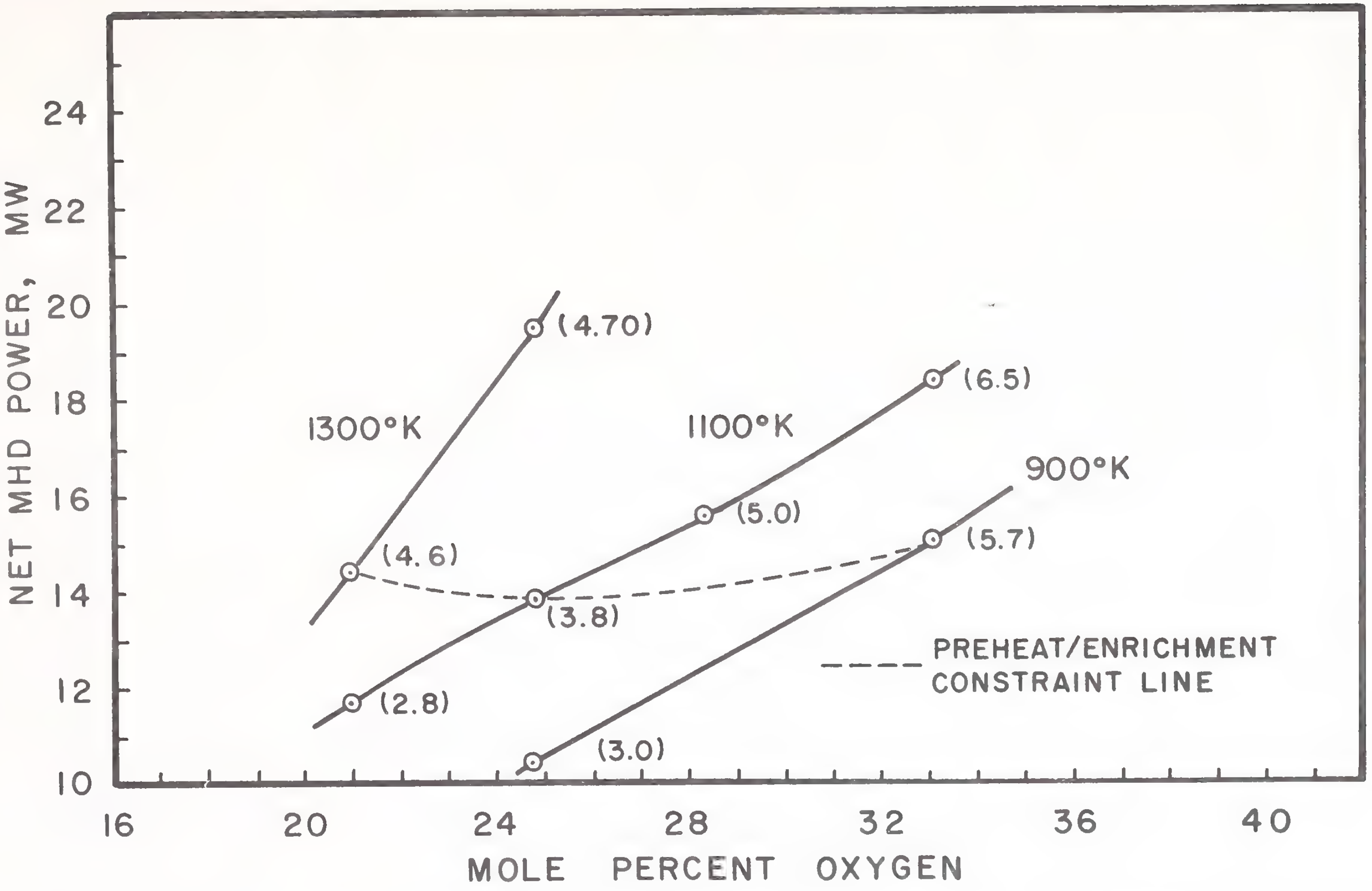


FIG. I-3: SUBSONIC GENERATOR PERFORMANCE MAP

recovery/seed recovery boiler (HRSR) is a design patterned after the one outlined by Bolek and Blackman, of Babcock & Wilcox, for the Engineering Test Facility.[13] The design also incorporates a number of suggestions from P. B. Probert,[14] also of Babcock and Wilcox.

The concept is illustrated in Figure 1-3. It consists of a suspended waterwall furnace of rather conventional design, with the MHD flow entering near the refractory lined walls in the lower part of the furnace. The lower furnace (below the secondary air injection ports) is sized to retain the flue gas for approximately two seconds at temperatures above 2500°F. This is to allow time for sufficient NO_x decomposition to meet regulatory standards. Secondary combustion air is injected at the top of the lower furnace, with enough momentum to promote good mixing. The upper furnace walls and roof are bare metal waterwalls. This eases the problem of clinker formation in the upper furnace where the slag particles may be wetted with condensing seed. Provision is also made for flue gas recirculation, to be injected at the secondary air windbox. The purpose of this is to provide some control over the heat flux distribution between the upper radiant surfaces and the following convective surfaces. Perhaps more significantly, this can be used to affect to some degree the composition and location of seed/ash deposition in the subsequent stages.[14]

Entering the convective pass, the gas first passes through the final superheater stage (SH2). The gas flow is then split into two passes, called the steam leg and the air leg (see Figure 3). The purpose of this is to provide a method of varying the heat flux balance between the reheat steam and the oxidant preheater. Dampers are provided at the cold end of each leg

to achieve this control. Entering the steam leg, the gas first flows over a pendant reheat section, then turns downward and passes through the first superheat section and the first reheat section. There, the gas turns and is directed to the electrostatic precipitator (ESP) and the tubular low temperature oxidant heater.

The gas entering the air leg passes through a series of pendant oxidant heaters, then turns downward and passes through the first superheat stage, then through the first oxidant heater stage. The gas then passes through the air leg damper, rejoins the steam leg gas flow, and proceeds to the ESP and tubular oxidant heater. The steaming order for the main steam flow starts with the feedwater being diverted at the first feedwater heater, and directed to the MHD power train as cooling water, after which it passes into the steam drum, and is evaporated in the waterwalls and floor of the lower and upper furnace. The saturated steam from the drum is next split into two streams, and directed through the SH1A and SH1B stages. The flows rejoin and are directed through the floor, walls, internal partition, and roof of the convection pass. The steam then passes through a spray attemperator in route to the finishing superheater, SH2, and hence to the turbine. The reheat steam flow passes serially through RH1 and RH2, with attemperation just before RH2. The oxidant flow first passes through a tubular, low temperature, oxidant heater (not shown), and then to the intermediate temperature oxidant heater stage, OH1, and hence to the high temperature oxidant heaters, OH2 and OH3.

The small + signs in Figure 3 indicate locations where provision will be made for soot blowers, i.e., steam lines, control conduits, waterwall

penetrations, etc. will be installed. It is anticipated that no more than half of these ports will be fitted with soot blowers initially, then they will be moved around, or additional ones added, based on operating experience. The first two bins in the convection pass will be collecting primarily wet seed/ash mixtures, while the last bin of the horizontal pass, the vertical pass, and the ESP will operate dry. The recent Argonne experience with ash collection[15] suggests that this will be workable as long as the tube spacing is kept wide, and materials are selected in accordance with the recommendations in Reference 16.

The boiler is suspended from the top in the conventional manner, and the MHD power train is solidly mounted to the floor. This requires some sort of a slip joint at the interface between the diffuser and the floating boiler. A slip joint has been designed, which involves both a water-cooled backplate attached to the diffuser, and a room air purge of the joint interface. This combination should keep the joint adequately cool and clean for reliable operation.

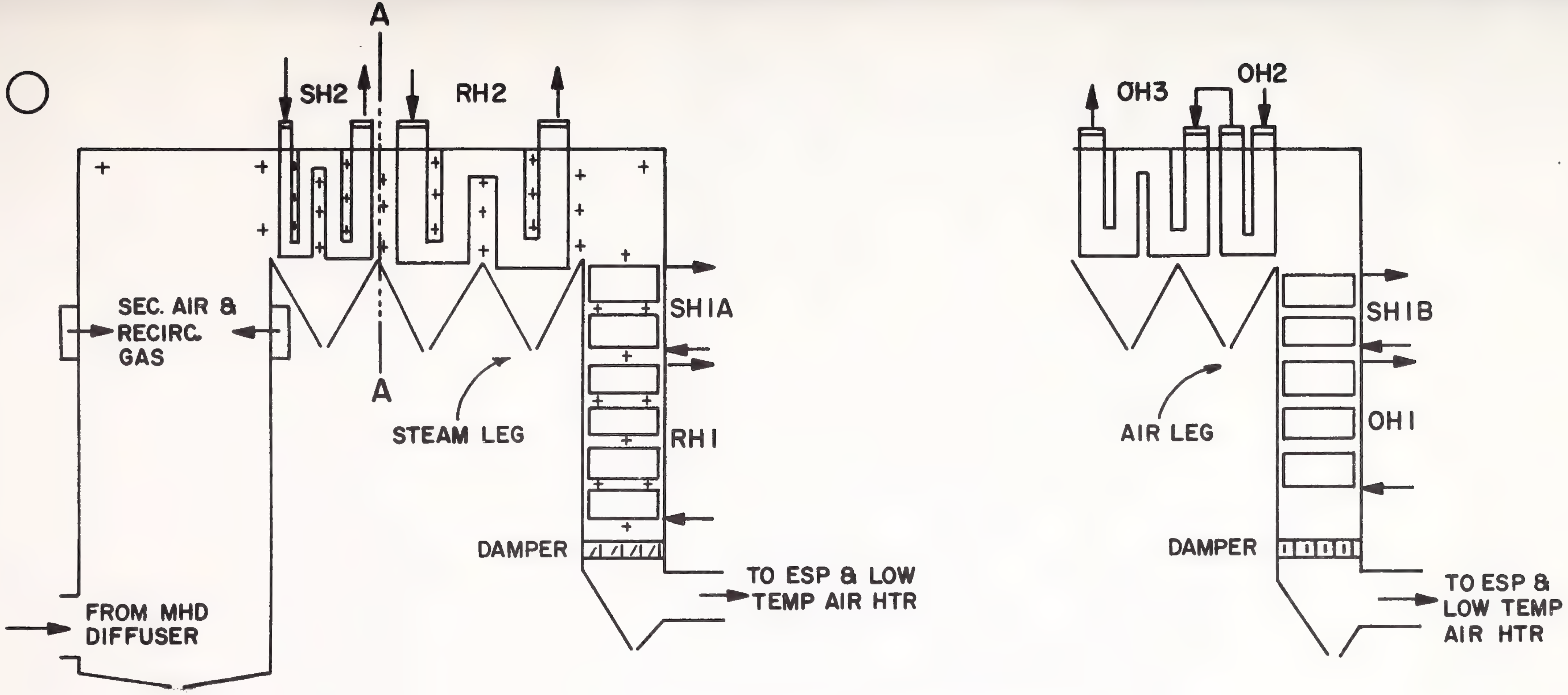


FIGURE 1-4: CORETTE HRSR BOILER PROFILE

2.0 DESIGN REQUIREMENTS

2.1 MHD System

2.1.1 Coal-Fired Combustor and Nozzle

The coal-fired combustor should be designed to burn Montana Rosebud coal dried to 5% moisture content, at a flow rate of 79,480 lbm/hr (10.0 kg/sec), and a combustion pressure of 5.83 atm, with an oxidizer flow rate of 366,030 lbm/hr (46.16 kg/sec). The combustor should accept a seed flow rate of 7,870 lbm/hr (0.992 kg/sec) of dry potassium carbonate and should reject at least 85% of the slag. Since the combustor will be at a 21 KV electric potential during MHD power generation, some form of electrical isolation must be provided to isolate the support structure and the various supply systems from this high electrical voltage. The combustor should be designed to operate at a stoichiometric equivalence ratio of 0.85, and should deliver a reasonably uniform flow at the nozzle entrance. The second-stage combustor and MHD channel walls should be constructed of non-ferromagnetic materials and should be water-cooled, using demineralized water to provide the required electrical isolation.

The function of the nozzle is to accelerate the gas flow to a Mach number of 1.2 at the nozzle exit. The nozzle walls also should be water-cooled and should be constructed of non-ferromagnetic material.

2.1.2 MHD Generator

The MHD generator should be of the supersonic, diagonal conducting wall type, 10 meters in length, with the approximate internal dimensions as shown in Table 1-3. The exact internal and external dimensions will be determined in part by constraints on the magnet geometry, as explained below. The generator will be of the linear type, with segmented electrodes on opposite walls. The electrode spacing and pitch should be such as to ensure that the insulating regions do not break down due to Hall field effects or excessive arcing. It is suggested that the Hall field and transverse current density should be limited to the values $(E_x)_{crit}$ = 2500 volt/meter and Jy-crit = 1 Amp/cm^2, to ensure that this condition is met. The generator should be constructed of non-ferromagnetic materials and should have water-cooled walls, and should operate with an enthalpy extraction of at least 10%.

2.1.3 Diffuser

The function of the diffuser is to decelerate the high-velocity flow out of the generator and to recover as much of the stagnation pressure as possible. The diffuser will consist of two sections: A uniform supersonic recovery section and a diverging subsonic recovery section. The diffuser will be designed to give an exit static pressure of 1.0 atmosphere (absolute) to minimize stagnation pressure losses due to shock waves and viscous wall effects. The diffuser should be constructed of non-ferromagnetic materials and should have water-cooled walls.

2.1.4 Superconducting Magnet System

This description applies to the conceptual design of a magnet system to provide the magnetic field required for a supersonic MHD channel intended to produce approximately 29 MWe.

The magnet should have a rectangular bore, a 10 meter active length, and a warm bore liner consisting of a water jacket through which cooling water is pumped. It should be designed to give a peak field of 4.5 Tesla. Significant performance benefits can be realized by carefully tailoring the magnet bore size, bore aspect ratio, and bore divergence to the generator geometry. Therefore the design efforts for the magnet and the MHD channel should proceed in tandem, with close interaction between the two efforts.

The system consists of the magnet and accessory equipment, with subsystems as listed below:

- Magnet assembly, including water-cooled warm bore liner
- Cryogenic support equipment
- Power supply and magnet discharge equipment
- Vacuum pumping equipment
- Protection/control equipment and instrumentation
- Cryogenic system

2.1.4.1 Magnet Assembly

The magnet assembly consists of liquid helium cooled superconducting coils of copper-stabilized-niobium titanium in a cryogenically-insulated vacuum jacket enclosure with a cavity extending through the center horizontally, and open at both ends. A water-cooled warm bore liner is provided inside the cavity. The outline dimensions of the magnet assembly and the dimensions of the cavity inside the warm bore liner, which diverges from plasma upstream (inlet) to plasma downstream (exit) end, are shown in Figure 2-1. The cavity with the water-cooled warm bore liner is designed to house the MHD channel, which is inserted and withdrawn from the large exit end opening. The magnetic field in the cavity is oriented in a primarily horizontal direction perpendicular to the long axis of the cavity. The magnet does not incorporate a ferromagnetic flux-return-path or other means to reduce fringe magnetic fields. The magnet is designed to be stationary, permanently mounted on a foundation provided as a part of the power plant facility. Design characteristics are summarized in Table 2-1. The windings are designed to produce the on-axis profile shown on Figure 2-2.

2.1.4.2 Cryogenic Support Equipment

The cryogenic support equipment consists of a helium refrigerator/liquefier, a helium compressor package, storage tanks, heat exchangers, transfer lines and controls as required. This equipment provides initial cooling of the superconducting magnet windings, maintains them continuously at liquid helium temperature during facility operating and standby periods, and warms the

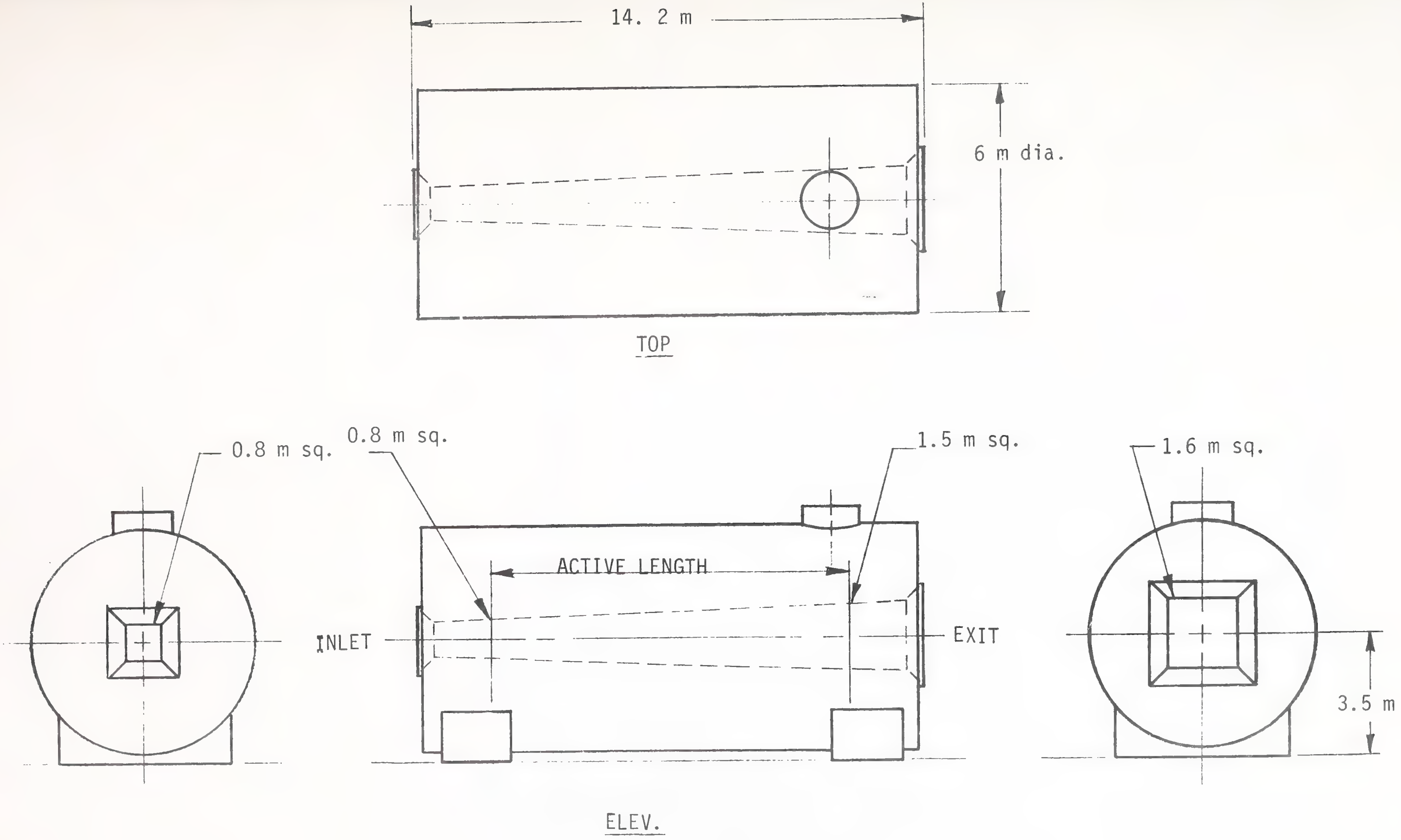


Figure 2-1 -- Superconducting Magnet Dimensional Schematic

TABLE 2-1
MAGNET DESIGN CHARACTERISTICS

Magnetic Field:	
Peak on-axis field	4.5T
Active field length	10 m
Field at start of active length	3.6T
Field at end of active length	2.7T
Dimensions:	
Aperture, warm bore inlet*	0.8 m x 0.8 m
Aperture, start of active length*	0.8 m x 0.8 m
Aperture, end of active length*	1.5 m x 1.5 m
Aperture, warm bore exit*	1.6 m x 1.6 m
Vacuum vessel overall length, including water-cooled warm bore liner	14.2 m
Vacuum vessel outside diameter	6 m
Winding Characteristics:	
Design current	20,000 A
Winding current density (J)	1.4×10^7 A/m^2
Ampere turns	15.2×10^6
Inductance	3.5 henries
Stored energy	700 MJ
Weights:	Tons
Conductor	75
Substructure	60
Superstructure and coil containment vessels	125
Thermal radiation shield, cold mass supports, etc.	20
Vacuum vessel	80
Miscellaneous	10
Total Magnet Weight	370

*Inside water-cooled warm bore liner

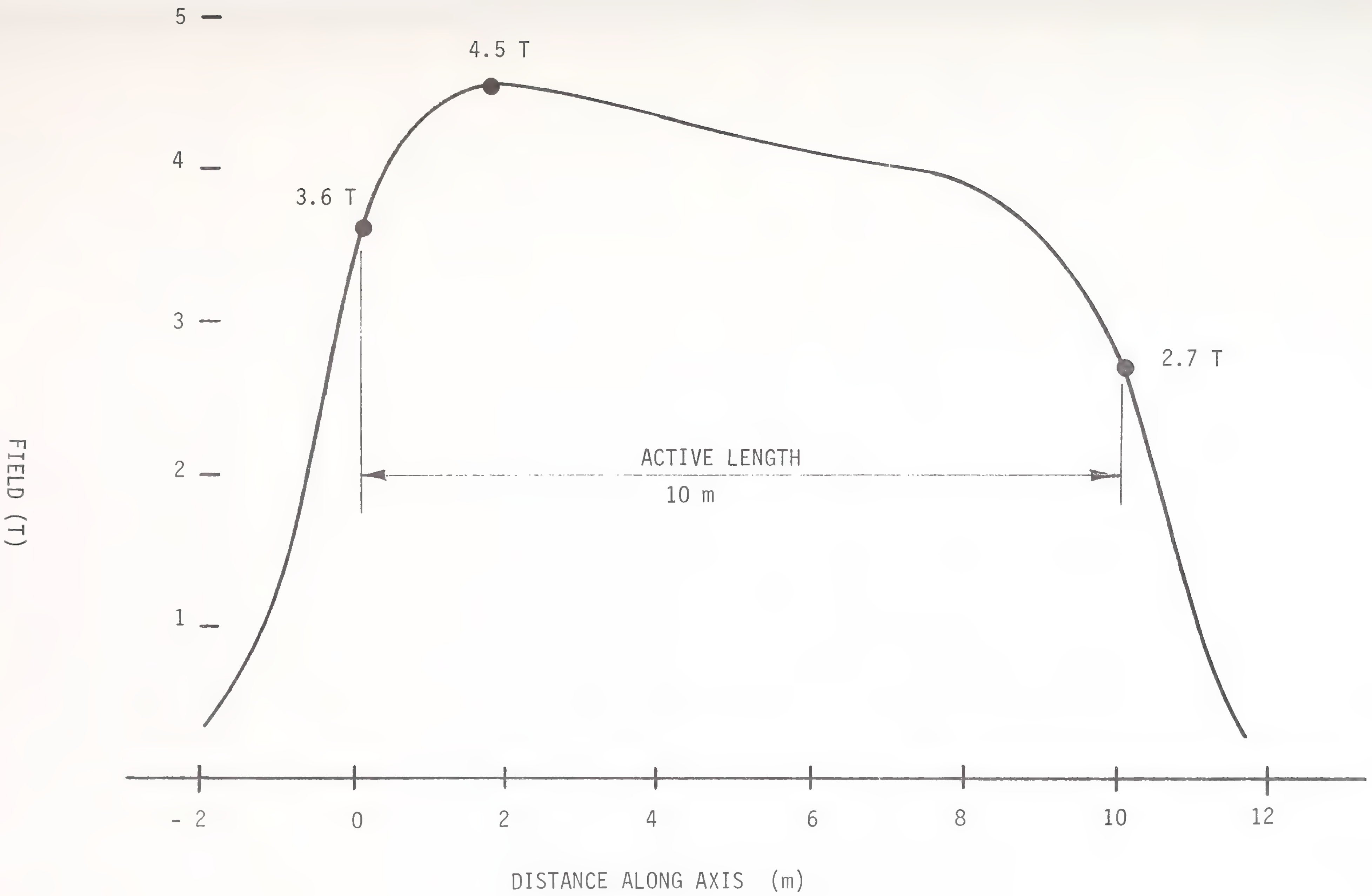


Figure 2-2 -- Curve of On-Axis Field Vs. Distance Along Axis

windings when an extended dead plant condition is anticipated. Liquid nitrogen obtained from the air separation unit is used as a cooling medium in the SCM cooling process.

2.1.4.3 Power Supply and Utility Requirements

The power supply and discharge equipment consists of a rectifier-type DC power supply, discharge resistors, circuit-breakers and controls as required for charging the magnet, maintaining it at the desired field strength during MHD generator operation and discharging it under both normal and emergency (fast) shut-down conditions. Utility requirements describing electric power, cooling water, and liquid nitrogen are summarized in Table 2-2.

2.1.4.4 Vacuum Pumping Equipment

Vacuum pumping equipment consists of diffusion pumps and mechanical pumps for evacuating the magnet vacuum vessel prior to and during initial magnet cooldown and for removing from the vacuum vessel any helium leakage that may occur from the coil container during magnet operation. A utility vacuum pumping system for servicing the cryogenic support equipment is also provided.

2.1.4.5 Protection/Control Equipment

Protection and control equipment consists of instrumentation to detect abnormal conditions in the magnet system and controls to automatically

TABLE 2-2

MAGNET SYSTEM UTILITY REQUIREMENTS

Electric Power (60 Hz):	Voltage	Power Requirements	Phase
Power supply - Maximum charging & starting	4160 V	750 KW	3
- Steady state of operation	4160 V	250 KW	3
Refrigerator/liquefier	220 V	8 KW	3
Refrigerator compressors	440 V	350 KW	3
Utility vacuum pump	220 V	15 KW	3
Diffusion pumps, main vacuum (2)	440 V	24 KW	3
Fore pumps, main vacuum (2)	440 V	20 KW	3

Cooling Water (80°F max., 50 psig except 100 psig for warm bore liner):	
Power supply (rectifiers; diodes)	25 GPM
Discharge resistors	30 GPM
Refrigerator compressors	110 GPM
Refrigerator/liquefier	3 GPM
Diffusion pumps, main vacuum (2)	5 GPM
Fore pumps, main vacuum (2)	5 GPM
Warm bore liner Steady-state	30 GPM
Emergency	150 GPM
Water-cooled power bus	25 GPM

Liquid Nitrogen Steady State 30 psig:	Liter/Hr
Refrigerator pre-cooling (steady-state)	110
Magnet radiation shield, transfer lines, etc.	40

activate protective measures. Low concentration (breathing type) oxygen detectors will be strategically located in the area for safety purposes.

Shielding will be used on the adjacent building walls to prevent magnetic fields from affecting either equipment or personnel. Provisions will be made to shield internal walls of the MHD building to allow maintenance access to other equipment located within the general area of the SCM. Included in the operations control area are instruments and controls to permit remote monitoring and control of major functions of the magnet and associated equipment. The additional local instrumentation and controls either will be located outside of the primary magnetic fields or shielded as appropriate.

The magnet system includes, in addition to the above subsystems, piping and wiring necessary to interconnect subsystem equipment items and to connect these items to the electrical, water, and air supplies as provided as part of the facility.

2.1.4.6 Cryogenic System

The magnet is contained in a cryostat, a superinsulated winding containment vessel, which is also filled with liquid helium to maintain a superconducting temperature of 4.1°K in the magnet coils.

The helium refrigeration system provides for the initial cooldown of the superconducting magnet and subsequently maintains the magnet operating temperature.

- Cooldown of the Magnet

The initial cooldown of the magnet is accomplished by reducing the temperature slowly to minimize stress. Gaseous helium cooled by liquid nitrogen exchange is recirculated to the magnet cryostat until a temperature of about 80°K is achieved.

The second stage cooling from 80°K to the operating temperature of 4.1°K or less is accomplished by liquid helium from the storage dewar. The rate of cooling is controlled by the liquid helium feed. Cooldown requires about 20 days to minimize thermal stress on the magnet. When the cooldown is complete, liquid helium accumulates in the magnet cryostat. When the operating liquid level is achieved, the system is ready for startup.

- Normal Operation

The process of reliquefying the helium begins during the cooldown. The liquid helium flows to the storage dewar which is maintained at atmospheric pressure. Liquid helium is either continuously or intermittently fed from the storage dewar into the magnet cryostat to maintain the cryostat's operating liquid level. The liquid nitrogen exchanger used on the initial cooldown step can also serve on a continuous basis to supply some of the refrigeration to the helium liquefier during sustained operational periods.

Boil-off is returned to the liquefier. When the reliquefier is dynamically balanced with vaporization rate, the compressor capacity is adjusted to maintain the vaporization pressure, i.e., at 4.1°K the vaporization gas must be maintained at atmospheric pressure. Any change in heat load will result in a change in gas flow which is automatically compensated by compressor output. The compressor is the basic inventory control.

Figure 2-3 is a basic flow diagram for a helium refrigerator-liquefier system. Helium inventory is contained in four places: (1) liquid in SCM cryostat; (2) liquid & cold gas in storage dewar (3) inventory in liquefier; and (4) the high pressure cylinder bank.

- Compressor Design Considerations

Special consideration should be given to the compressor beyond its duty as a liquefier; the compressor is the primary control device for a wide range of gaseous nitrogen flows from the SCM cryostat. A variable speed drive compressor or other means of wide range control, such as valve unloaders, should be used. Temperature control of the magnet cryostat is dependent upon vaporizing pressure. The compressor must be capable of maintaining at or near atmospheric pressure over the vaporizing helium liquid and replace the liquid in the storage dewar at the rate of withdrawal.

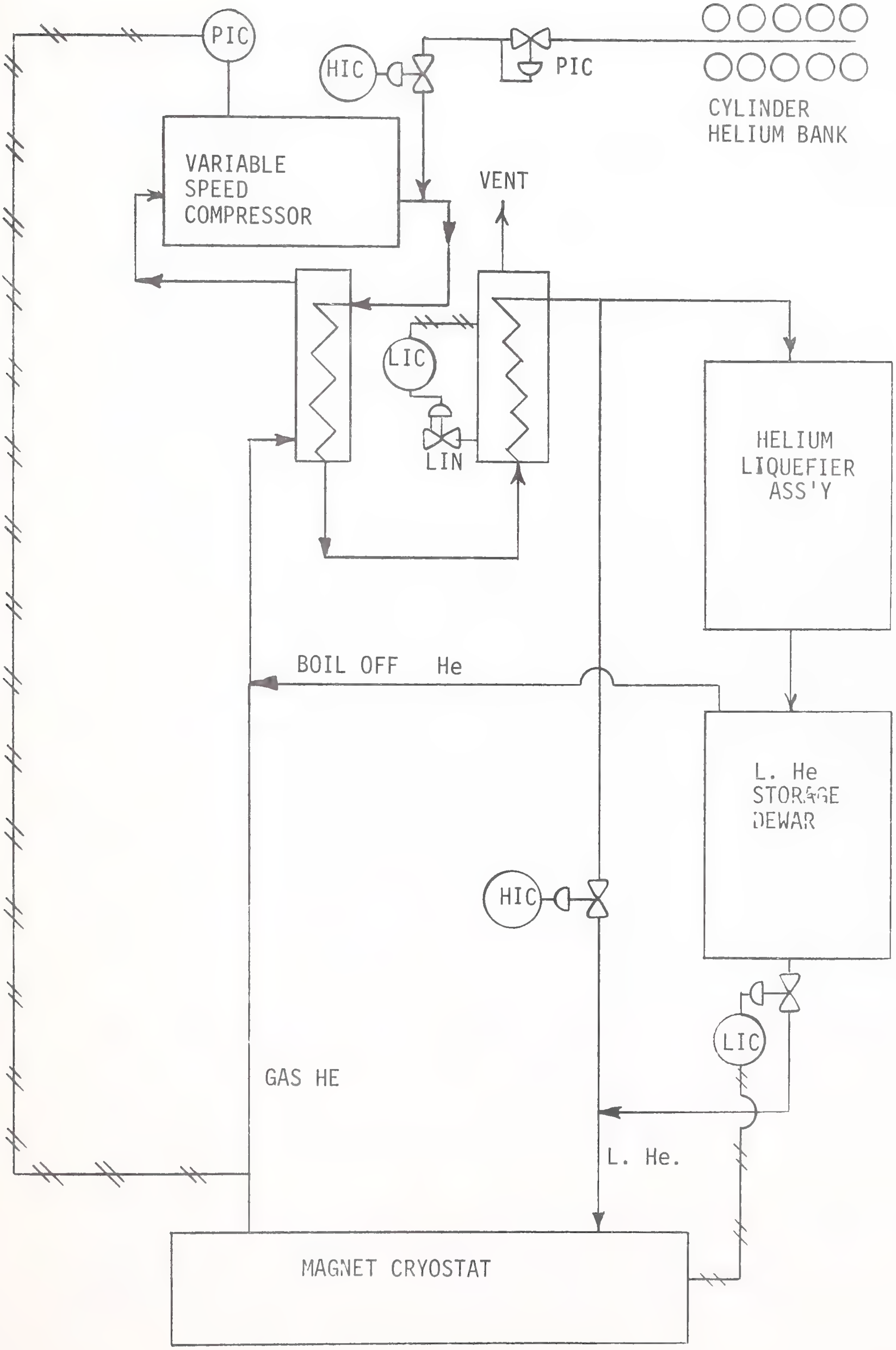


Figure 2-3 -- Helium Refrigeration System

- Storage Vessel (Dewar)

The storage vessel should be large enough to provide for major liquid replacement but sized to a minimum to reduce heat loss. A larger vessel has a lower heat leak as a percentage of the total volume, but the vessel would have a larger total heat leak and require more reliquefaction power as compared to a small vessel. The vessel will be minimum size, superinsulated, and liquid-nitrogen shielded to satisfy the requirement for minimum heat leakage.

To minimize heat leakage from the transfer pipelines, the storage vessel (dewar) should be located as close to the magnet dewar inlet as possible. A second floor location of the dewar and helium liquefier has been selected to achieve this minimum distance. Of equal importance, gravity-head permits the dewar to be maintained at atmospheric pressure for minimum boil-off in the cryostat during liquid transfer.

- Transfer Lines

Superinsulation and liquid nitrogen tracing is recommended on the transfer lines. Lines should be designed for low pressure drop on liquid supply to the cryostat and cold gas return to the liquefier.

Expansion bellows should probably be used except on very short pipe sections as the thermal shrinkage of the inner pipe versus the

outer jacket is substantial. Utilization of elbow movement for shrinkage is generally unsatisfactory and produces excessive heat leaks that are unacceptable operationally and also cause substantial increases in power costs.

Consideration should be given to requiring testing for liquid helium heat leak and integrity testing of installed pipelines by the fabricator. While this testing is expensive, a bad line will rapidly increase costs via heat losses or by replacement subsequent to initial installation.

Workmanship is equally important to design. The fabricator and all key equipment should be thoroughly checked-out before selection. Continuing inspection during fabrication is recommended.

o Air Leakage into Helium

Air leaks into the system would be frozen into air-ice thereby procuding pluggage that would shut down the system. Careful design and fabrication, preliminary purging by repetitive evacuation, and filling with gaseous helium to ensure system integrity are economically desirable.

o Magnet Power Leads

The 11,000 amp feeders are a major source of heat leak at the juncture into the cryostat. It is suggested that these leads be

liquid nitrogen cooled which provides the dual benefit of reduced conductor resistance and reduction of heat transmission into the cryostat.

- Portable Insulating Vacuum Pumping System

It is essential that a vacuum pumping equipment assembly be available to restore insulation vacuum on transfer lines, dewars, and cryostats.

The equipment should be mounted on a wheeled cart for maximum portability. The pumping equipment must be moved as close as possible to the equipment being evacuated for rapidity of transfer, thereby achieving the best vacuum. Vacuum systems piped to a central station are notoriously unsuccessful.

- Cylinder Storage System for Helium

A reserve storage of helium gas for loss makeup is recommended. At least 25 cylinders should be manifolded together for emergency makeup with 25 additional cylinders in reserve in anticipation of reasonable loss requirements. Larger amounts of storage are not recommended due to the air and water contamination experienced in low-pressure storage. Initial filling of the system would be accomplished by tank truck. Since these cylinders are reserve, they will not be refilled frequently and purchase rather than demurrage payments would be more economical.

2.1.5 Heat Recovery, Seed Recovery System

The functions of the Heat Recovery System are to generate steam from the exit combustion gases of the MHD power train and also to supply approximately 23 MW_t of oxidizer preheat. An additional requirement is that the bottom ash and fly ash (containing seed mixtures) must be removed and collected at several points throughout the system.

As shown on the configuration schematic, Figure 1-1, the MHD power train and heat recovery system will supply approximately 33% of the total steam requirement for the turbine generator. Steam generation will be accomplished through the use of water walls in the radiative section of the HRSR. Superheating for both primary and reheat steam will be accomplished by pendant type superheaters located in the convective region of the HRSR. The convective section is split into two separate legs in order to provide a means of controlling the relative balance between oxidizer heating and superheating. The two gas stream flow rates will be controlled by dampers installed near the bottom of each leg. Special design considerations will be made to alleviate the cold end corrosion and contamination problems associated with dampers located in these areas.

The radiant section of the heat recovery system will be designed to allow a 2 second gas residence time for equilibration of NO_x. Some flue gas recirculation will be required to regulate the temperature in the transition region at the end of the radiant furnace section and will be injected along with the secondary air.

Slag collection will be accomplished by employing a wet bottom ash type of collection system in the radiant portion of the HRSR. In the convective section of the HRSR, seed and ash material will be collected in a dry form; the possibility also exists for wet collection.

A major consideration during the actual design of the HRSR is going to be the allowances for expansion and contraction of the unit during operation. The support elevation of the HRSR should be at the elevation of the centerline of the MHD power train. That centerline and diffuser connection will be at a fixed point and unable to adjust to HRSR movement therefore requiring care in the design of the connections.

Generation of low grade steam during startup of the HRSR or during initial firing of the MHD power train would be fed into a turbine bypass system to avoid the problem of two varying grades of steam being fed to the Corette turbine-generator. The turbine bypass systems would be designed as a separate system with the capability of addressing the superheat and reheat steam requirements of the turbine-generator during the startup operation. Consultation with both the turbine-generator manufacturer and HRSR supplier would be required during the preliminary design phase.

The superheat and reheat steam that is supplied by the HRSR system must be closely matched in pressure and temperature to the respective steam flows that are supplied by the Corette boiler. The required exit steam conditions at design point operation are shown in Table 2-3.

Table 2-3

BOILER STOP VALVE STEAM CONDITIONS FOR CORETTE BOILER AND HRSR

	Corette	HRSR
Superheat Steam	7.462×10^5W 1481H 1905P	3.675×10^5W 1481H 1905P
Inlet Reheat	6.363×10^5W 1345H 494P	3.134×10^5W 1345H 491P
Exit Reheat	6.363×10^5W 1524H 481P	3.134×10^5W 1524H 481P
Feedwater	7.500×10^5W 445H 463F	3.692×10^5W 445H 463F

NOTE: In the above table the letters W, P, and H have the following interpretation:

W lbm/hr

P lb/in^2 (abs)

H BTU/lbm

Since both the existing Corette boiler and the HRSR system will be generating steam during combined cycle operation, a control system will be provided to merge the superheat and reheat steam flows. This control will be accomplished by adjusting the amount of feedwater flow into each system based on steam flows, firing rates, furnace air flows, etc. and by maintaining the reheat balance by the use of steam valves in each of the two cold reheat legs.

2.1.6 Inverter

The configuration analysis predicts a DC output from the channel of 20.5KV and a power output of 28.7MW-DC. The purpose of the inverter is to convert the DC output to AC and to refine it to a quality that will be compatible with commercially produced power. The design of the inverter will accommodate 30MW of DC power at the input and through the use of taps in the transformers the AC inverter output voltage will be compatible. (See Figure 2-4).

The inverter for the Corette retrofit will be quite similar to the one at the Component Development and Integration Facility (CDIF) in Butte, Montana, except for some refinements and improvements noted in this text.

Except for the switchgear, the CDIF inverter is capable of 8 MW to 10 MW of through-put. The CDIF installation is receiving approximately 10,000 volts DC from the channel and experiences a voltage rise to 11.6 KV at the AC output of the inverter. If this ratio holds true in the planned installation

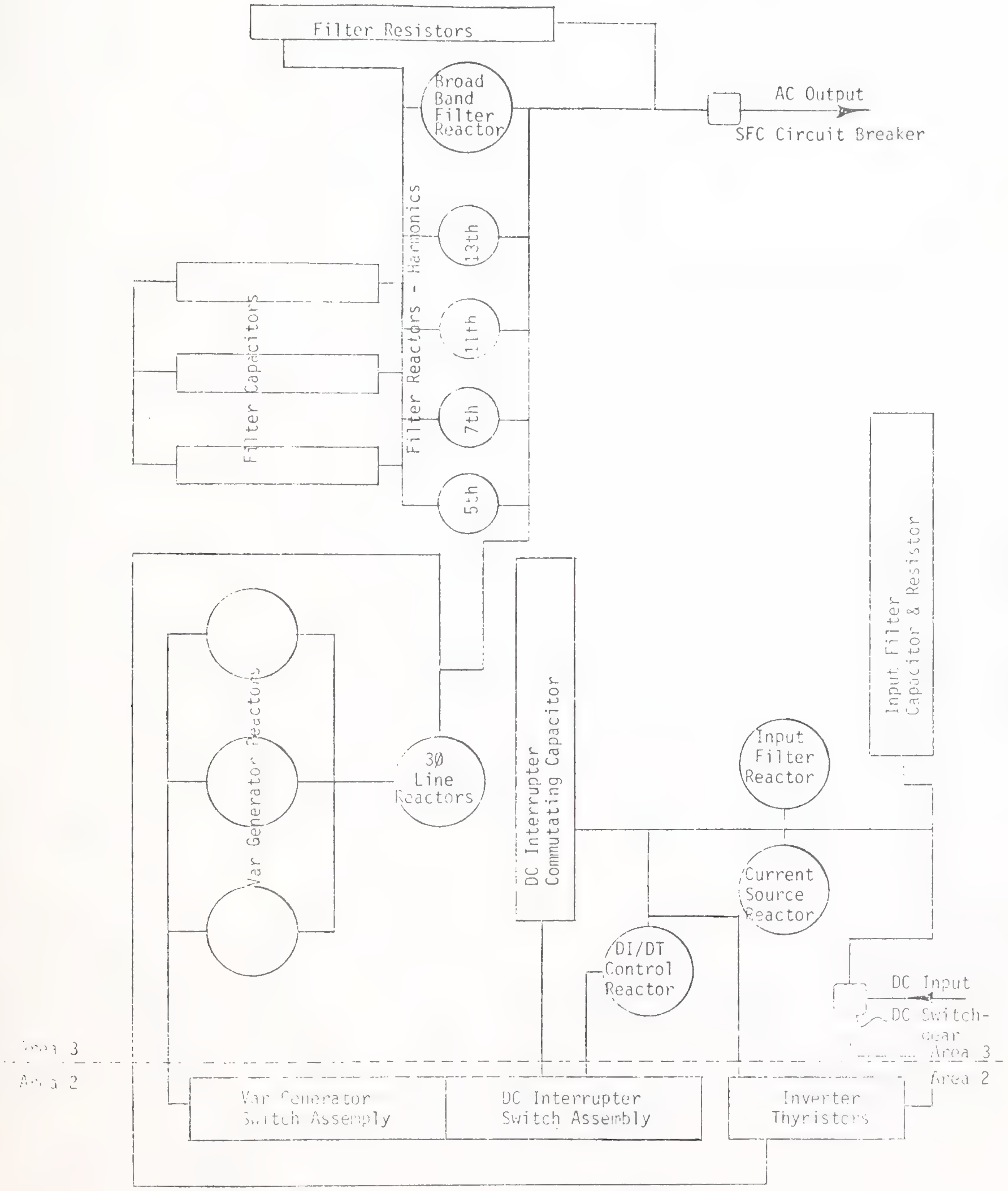


Figure 2-4 -- Corette ATS Inverter Schematic One-Line Diagram

an input of 20.5 KV to the inverter will provide an AC output of 23.8 KV and standard equipment can be used by using a 5% tap in the transformers.

The output from the channel will be consolidated on two approved isolated phase copper buses rated at 25 KV and 2000 amperes. This bus will be fully protected from any contact with external objects and there will be no possibility of a fault occurring on it.

A suggestion made by the Electric Power Research Institute (EPRI) is to use two 6 pole rectifiers to provide a 12 pulse unit. This would require only one half the equipment in the harmonic and power factor correction section as is currently in area 3 at CDIF.

Similar to the CDIF installation, the inverter system will be divided into three areas. Area 1 is the control section, Area 2 the converter switching assemblies and VAR generator section, and Area 3 the harmonic and power factor correction section. Areas 1 and 2 of the proposed facility should be double the size of those at CDIF and Area 3 should be about 1.5 times as large as that at CDIF.

Experience with Area 2 at CDIF indicates a need to install this equipment in a long continuous line. This section of the present CDIF building is 35 ft wide, therefore, the ATS building will be 70 ft in width. It appears that a building 70 ft by 125 ft with an eave height of 24 ft will be adequate. The inverter building will be located adjacent to the building that houses the channel in order to keep to a minimum the length of bus from the channel to the inverter.

Additional input from West, SRI, and EPRI has provided a solid basis for the initial design of the inverter.

2.1.7 Instrumentation and Control

Some of the general considerations that arise in designing a control system include:

- o Who will exercise control?
- o What modes of control are needed? and,
- o How should the control system be organized?

Since it is planned to integrate the MHD system with an existing utility power plant, the ultimate control will need to reside in the hands of the utility plant management. In the case of an MHD plant combined with a conventional steam plant of similar size, one suitable control scheme would be to implement a supervisory control layer with ultimate control over both plants. The supervisory layer would be operated by the utility plant operator. MHD testing would be carried out with the consent of the Corette plant utility superintendent.

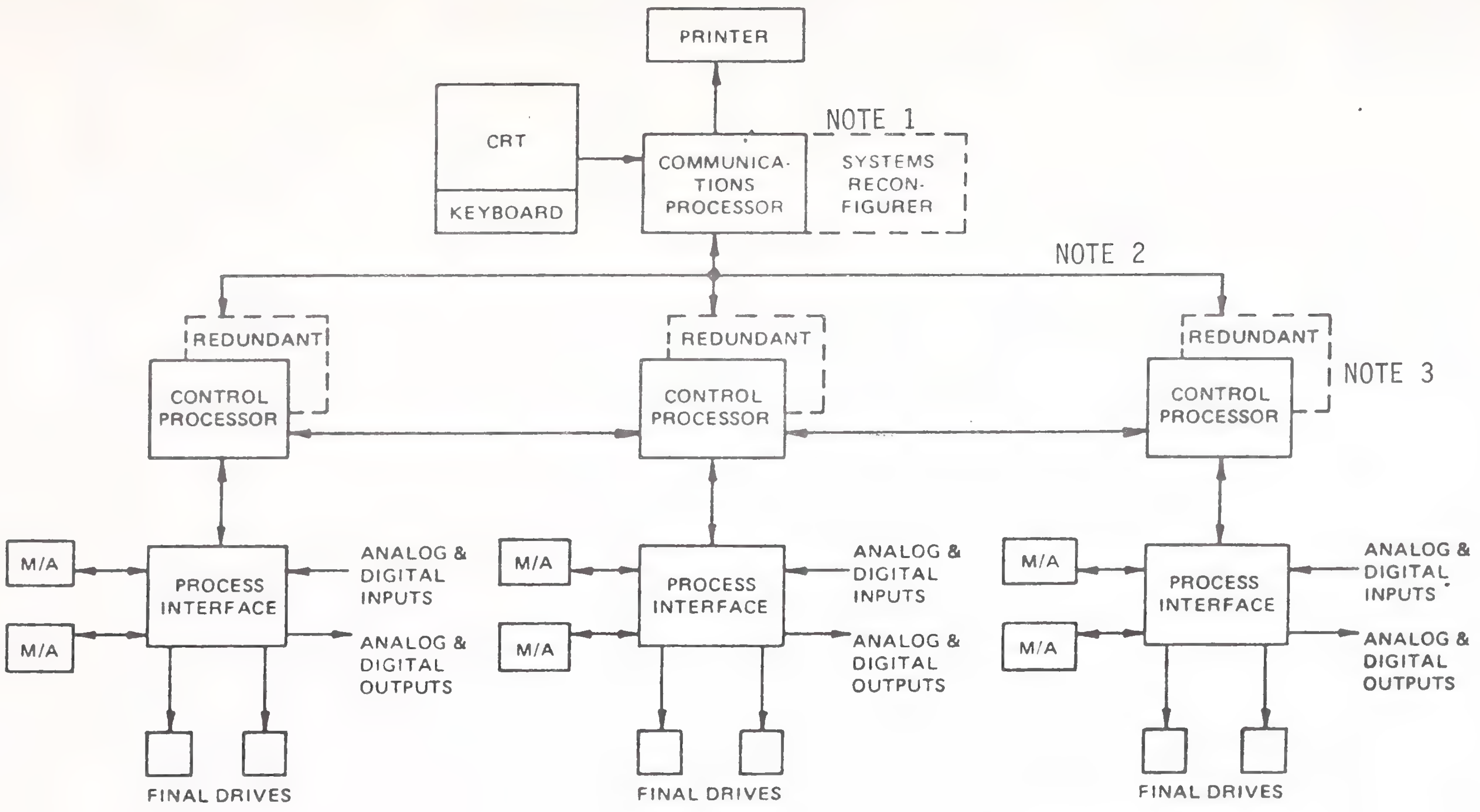
Several modes of control will be needed in each of the two operating situations - MHD testing and utility-controlled power production. For initial MHD testing it will probably be necessary to operate the MHD plant in a stand-alone mode with the utility plant off-line. This will minimize the complexity of the system and yield the highest probability of a successful MHD test. In later test stages and during combined utility operation, it

will be necessary to demonstrate combined plant controllability and MHD flexibility by operating the entire plant together. Thus, the needed operating modes include startup (cold, warm, and hot), baseload (emphasis on stability and detailed controllability), transient, shutdown, and emergency for either single plant (MHD or existing conventional) or both.

The multiple modes of control needed for the facility and its status as a test facility require a flexible control system. Ideally the control system should be capable of modification to implement new and/or better control schemes as a greater understanding is gained during testing. These modifications should not require major efforts.

A Distributed Digital System (DDS) will be used for instrumentation and control. Each process system or subsystem will be under the control of a local microprocessor/microcomputer. The microprocessor set points will be determined by a supervisory computer that can act automatically or under manual operator control. This type of system yields the degree of flexibility that is appropriate to a test facility. Control algorithms can be modified from the supervisory computer and downloaded to the local microprocessors to implement desired changes in system operation. See Figure 2-5 for a diagram of this control scheme.

The control scheme consists of a supervisory computer control system with cathode ray tubes (CRTs), keyboard, and control panel interface to operators and a high-speed communications link to the local subsystems control microcomputers that have real-time control over their respective systems. The use of this high-speed, multiplexed link eliminates the need for large



CONTROL SYSTEM OVERVIEW WITH REDUNDANT CONTROL PROCESSORS

Notes:
1. Supervisory computer
2. High speed data communications link
3. Local microcomputers, one for each system

Source: Westinghouse Microprocessor Control System Literature

Figure 2-5

numbers of wires carrying individual signals and thus removes a constraint on control room position. Since the supervisory computer control system does not need to be near the MHD plant that it controls, it can, and is recommended for placement in the existing Corette control room.

The local microcomputers perform the detailed control of their processes with only overall direction from the supervisory computer. The local microcomputers handle all raw data from sensors and send along to the supervisory computer only that data which is needed for the overall control function (including feedback to show the completion of commands; e.g., valve position sensor data.) The supervisory computer will maintain a sequence-of-events log for analysis of cause and effect relationships resulting in alarm conditions. Redundant computers will be used to increase on-line reliability and ease of repair.

The eleven MHD processes that are under the control of the supervisory computer are detailed below and listed in Table 2-4.

2.1.7.1 Primary Oxidizer Flow

The air separation unit (ASU), ASU compressors, blend air compressor, and mixer are the major components of the oxidizer system. The ASU will be self-contained and only its operating point will be controlled by the DDS. The primary controls on oxidizer flow will be the specified thermal heat rate and the specified stoichiometry.

Table 2-4

MHD PROCESS CONTROL REQUIREMENTS

Item	Function
Supervisory Computer (SC)	Controls local subsystem microcomputers and interacts with plant operator.
Primary Oxidizer Flow Control Microcomputer	Local, real-time control of all primary oxidizer system components; feedback to supervisory computer (SC) as appropriate.
Coal Flow Control Microcomputer	Local, real-time control of all coal handling and feeding system components; feedback to SC as appropriate.
Combustor and Channel Microcomputer	Feedback to SC as appropriate for determining combustor and channel operating conditions.
Superconducting Magnet Control Microcomputer	Local, real-time control of magnet and its associated cryogenic and electrical systems; feedback to SC as appropriate.
Flow Train Heat Removal Microcomputer	Feedback to SC as appropriate for determining heat transfer and flow train status.
Secondary Air Flows and Recirculation Gas Control Microcomputer	Local, real-time control of secondary air flow, recirculation gas and temperature; feedback to SC as appropriate.
Steam Generation Control Microcomputer	Local, real-time control of HRSR boiler feedwater flow and chemistry; feedback to SC as appropriate.
MHD Inverter Control Microcomputer	Local, real-time control of MHD Inverter; feedback to SC as appropriate. This control microcomputer is supplied by the Inverter manufacturer.
Protective Equipment Microcomputer	Monitor protective systems and sensors; feedback to SC as appropriate.

2.1.7.2 Coal Flow

The entire coal feeding system including delivery, crushing, drying, lock hopper operation, and transport to the combustor will be included herein. An accurate measurement of coal flow rate is essential for proper combustor operation, and special attention will be given to this equipment in subsequent design phases. The primary control on coal flow rate will be the specified thermal heat rate. For accurate control of combustion characteristics and slag handling an on-line coal analysis instrument is recommended.

2.1.7.3 Combustor

Flame temperature and cooling water heat extraction will be monitored to determine combustor performance parameters. The supervisory computer will use these measurements in adjusting oxidizer and coal feed rates.

2.1.7.4 MHD Channel

No direct control is exerted over the channel; but measured parameters of voltage and currents at selected electrodes, conductivity, and power output are used in feedback loops to the combustor feeds and superconducting magnet.

2.1.7.5 Superconducting Magnet

The magnet and its associated cryogenic and electrical systems will be controlled together. The helium liquefied subsystem is self-contained and will be controlled by a helium-demand signal.

2.1.7.6 Flow Train Heat Removal

Heat transfer from each component -- combustor, nozzle, channel, diffuser -- will be measured and used to assess wall properties such as slag layer thickness and wall erosion. Changes in wall heat transfer can signal impending wall breakdown or excessive slag buildup.

2.1.7.7 Secondary Air Flow

The secondary air blower and heat exchanger will be controlled to produce the desired secondary combustion as determined by oxygen measurement in the stack. The secondary air preheat will be controlled by adjustment of hot exit gas flow to the secondary air heat exchanger.

2.1.7.8 Recirculation Gas

Exhaust gas will be recirculated to the radiant furnace to aid in NO_x control. This gas stream will be controlled by blower speed based on achieving the desired secondary combustion temperature.

2.1.7.9 Steam Generation

Feedwater and reheat steam to the boiler will be controlled by flow control valves to regulate the amount of steam produced. Control of the valves will be done by sensing the ratio of the steam flow between the two boilers. Coal feed rates will also be controlled as necessary to maintain the energy balance with the steam produced. Feedwater chemistry will be adjusted as necessary to produce the needed water quality in the boiler.

2.1.7.10 MHD Inverter

The inverter is a self-contained system that will be operated under the control of the supervisory computer. Power input and output and cooling water temperature will be monitored by the supervisory computer.

2.1.7.11 Protective Equipment

Many of the MHD systems will have auxiliary sensors for protective purposes. These protective systems will be interfaced to the supervisory computer and appropriate, automatic, action will be taken in the event of a system breakdown. For example, if the channel integrity monitoring system reports a leak in the channel wall, the combustor will be shut down on an emergency basis.

2.1.8 Data Acquisition

The data acquisition function will be handled by the same system that operates the instrumentation and control system. MHD performance parameters (electrode voltages and currents), power levels, heat balance, and input feed rates will be recorded for later analysis. Other parameters can also be recorded as it is determined they are required for system analysis.

The data acquisition system must be capable of taking and storing the data at rates sufficient to allow analysis and interpretation of events in the MHD

power train. Some data will have to be recorded at frequencies in the kilohertz range. Table 2-5 lists the points to be monitored in each system. The system must be capable of expansion and will receive other data inputs than those mentioned.

TABLE 2-5

POINTS MONITORED BY DATA ACQUISITION COMPUTER

System	Parameter	# Of Places	Frequency (Hz)
ASU Control	Control System Interface	2-10	1
	Flow Rates	2-6	1
	Pressure	2-6	1
	Temperature	6-10	1
Blend Air Compressor	Motor Speed	1	1
	Lubrication Flow	1-5	1
	Lubrication Temp.	1-5	1
Oxidant Mixer	Valve Position	1-5	10
	Flowrates	1-5	10
	O_2 Concentration	1	1
Coal Flow	Flowrates	2-5	10
	Delivery Pressure	2-5	1
	Dryer Temp.	2	1
	Valve Position	1-6	10
	Coal Ash %	1	1
	Coal C/H Ratio	1	1
Combustor	Flame Temp.	1	100
	Cooling Water Temp.	20-30	1
	Pressure	2	100
MHD Channel	Cooling Water Temp.	40-60	1
	Electrode Voltage	30-40	1000
	Electrode Current	30-40	1000
	Power Output	1	10
	Pressure	20	1
	Pressure	2	100
Superconducting Magnet	Magnet Temp.	10-100	1
	Magnetic Field Level	10-20	1
	Current	1-10	1
Electric Power Supply	Voltage	1	10
	Current	1	10
Helium Liquefaction System	Pressure	5-15	1
	Temperature	5-15	1
	Helium flow	2	1

TABLE 2-5

POINTS MONITORED BY DATA ACQUISITION COMPUTER (Cont'd)

System	Parameter	# Of Places	Frequency (Hz)
Flow Train Heat Heat Removal	Water Flow	3-10	1
	Water Temp.	3-10	1
Seed Flow	Flow Rates	3	1
Secondary Air Flow	Air Flow	2	1
	Air Temp.	1-3	1
	O_2 Level	1	1
Blower	Lube Oil Temp.	1-5	1
	Lube Oil Flow	1-5	1
	Speed	1	1
HRSR	Water Flow	2	1
	Valve Position	2-10	1
	Water Chemistry	3-8	1
	Pressure	10-15	1
	Temperature	15-25	1
MHD Inverter	Power Input	1	10
	Power Output	1	1000
	Water Flow	1	1
	Water Temp.	2	1
Protective Equipment	TBD	TBD (100)	TBD
Corette Plant	Electric Power	1	1
	Steam Flow	2	1
	Coal Flow	1	1
	Pressure	5	1
	Temperature	5	1

2.2 MHD Interface Systems

This section discusses the equipment and processes necessary to support the operation of the MHD topping cycle.

2.2.1 Coal Preparation and Feed

The necessity of providing a consistent feed to the CFC requires a uniformly pulverized coal with a maximum moisture content of 5%. Both as received coal storage and prepared coal storage are required to support the various operational modes of the coal preparation system. An inerting atmosphere is necessary to prevent spontaneous combustion of the coal during the drying process. Separate discharge pipes on storage bins and the injection transport vessels are required to empty bins during operational problems. A method of weighing will be required; and a method of injecting the coal into the CFC will also be required to overcome the expected CFC pressures. A system independent of the Corette plant is required for coal drying, pulverizing, and injection. Any atmospheric discharges must meet existing environmental air quality standards. Table 2-6 is a summary of the properties of Montana Rosebud subbituminous coal as used at the DOE Chemical Equilibrium Workshop in September 1979 and adapted for this study.

2.2.1.1 Storage and Predrying

Two additional coal storage bunkers would be constructed at the northern end of the ATS facility. A new transfer point would be constructed at the existing coal reclaim system by No. 5 coal conveyor to provide raw coal feed

TABLE 2-6

MONTANA ROSEBUD SUBBITUMINOUS COAL

	Nominal Values	Range of Values
Ultimate Analysis % Moisture Free		
Hydrogen	4.6	2.8 - 6.4
Carbon	65.6	61.8 - 69.4
Nitrogen	1.0	0.9 - 1.1
Oxygen	14.4	12.4 - 16.4
Sulfur	1.1	0.4 - 5.0
Ash	13.0	6.0 - 17.0
Ash Analysis, %		
SiO_2	47.5	22 - 55
Al_2O_3	21.1	12 - 25
CaO	14.4	5 - 20
Fe_2O_3	7.8	2 - 20
MgO	4.6	2.2 - 7.0
TiO_2	0.8	0.2 - 1.4
K_2O	0.7	0 - 1.5
Na_2O	0.4	0 - 1.2
P_2O_5	0.4	0.1 - 0.7
Proximate Analysis, Moisture Free		
Volatile	37.7	34 - 42
Fixed Carbon	47.6	43 - 52
Moisture, as Received, %	25.5	20 - 35
Heating Value		
Dry BTU/lb	11,300	10,650 - 11,950
Fusions		
Initial Deformation Temp, °F	2244	1960 - 2420
Softening Temp, °F	2278	1990 - 2470
Fluid Temp, °F	2362	2040 - 2520

to the bunkers. This concept would take advantage of the existing coal handling and reclaim system which was initially designed to handle two units similar in size to the Corette plant. Site layouts show the interface transfer point at the coal reclaim tunnel; however, an optional transfer point could be located along No. 5 coal conveyor. Figure 2-6 identifies the primary equipment that will be required in the coal preparation system. Table 2-7 summarizes the major equipment capacities and flow characteristics.

A coal feeder would meter the raw coal from the coal bunkers to the crusher where the coal is reduced to 1/2" maximum size and fed into the coal predryer. The coal predryer reduces the nominal moisture of the Montana Rosebud subbituminous coal from 25.5% to 12% using a self-contained coal pulverizer and firing system for air drying. Preheated nitrogen will be used to temper the air back down to drying temperatures. That nitrogen gas will be as generated in the air separation plant and heated in a nitrogen heater backpass leg of the HRSR. The exhaust from the coal predryer is routed through a baghouse system to remove particulates.

2.2.1.2 Pulverizing and Drying

The predryed coal will be transported by enclosed conveyor to pulverizers where the coal will be pulverized to a grind size of 70% through 200 mesh with completion of drying to 5% moisture. Two pulverizers would be required to provide adequate allowances for repair or breakdown of those units and to enable continued operation of the MHD power train. Originally, one pulverizer could be installed with provisions (area, conveying, electrical, control, etc.) for the installation of a second pulverizer when continuous operating conditions warranted it.

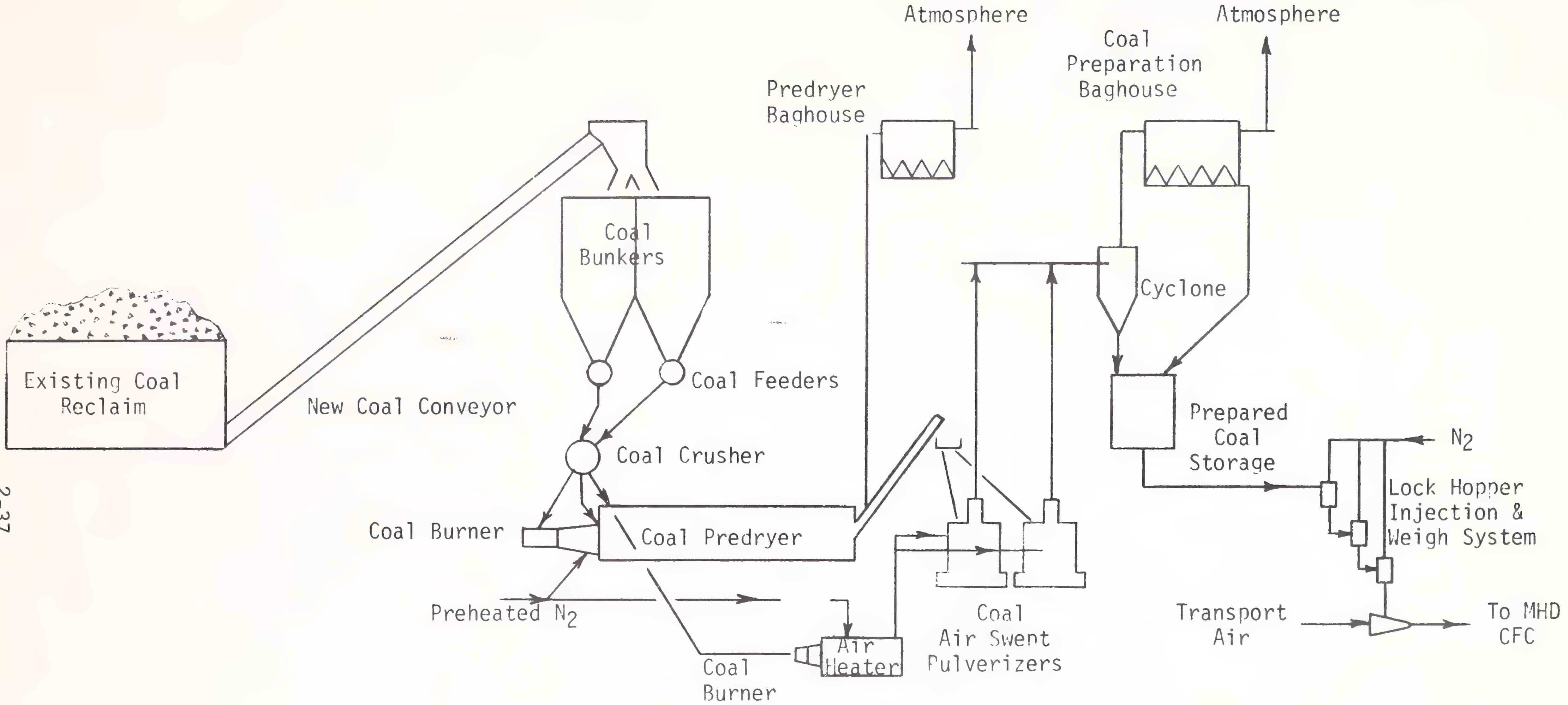


Figure 2-6 -- Coal Preparation & Feed System

TABLE 2-7

COAL STORAGE AND PREDRYING EQUIPMENT

Item	Quantity	Capacity (Each)	Nominal Operating Conditions
Coal Bunkers	2	400 Tons	
Coal Feeders	2	60 TPH	50.7 TPH (12.768 kg/s)
Coal Crusher	1	60 TPH	50.7 TPH (12.768 kg/s)
Coal Predryer with Nitrogen Tempering	1	60 TPH	Moisture Reduced From 25.5% to 12.0% 42.9 TPH (10.809 kg/s)
Air Swept Pulverizer with Air Preheater	1	50 TPH	Moisture Reduced From 12.0% to 5.0% 39.7 TPH (10.0128 kg/s)
Prepared Coal Storage Bin	1	40 Tons	39.7 TPH (10.0128 kg/s)
Injection System	1	45 TPH	39.7 TPH (10.0128 kg/s)

The pulverizers will use an airsweep drying system integral with their design and operation. The air heater will also use a self-contained coal pulverizer and firing system to preheat the air introduced into the pulverizer. An inerting atmosphere of nitrogen will be used to prevent spontaneous combustion of the coal as it is dried and transported throughout the coal preparation process. That nitrogen is also obtained from the air separation plant after it passes through the nitrogen heater in the HRSR. The nitrogen would have been exhausted to the atmosphere if it were not utilized in the coal preparation process. The coal preparation system is essentially an inert gas circulating/classifying system once the predried coal from the predryer is introduced into it. The coal should be dried to a constant BTU value to provide maximum stability in the coal-fired combustor, thereby providing a uniform plasma for MHD electrical generation.

As the dried pulverized coal entrained in the inert gas exits the pulverizer it is routed to a cyclone separator. The coal is directed to a prepared coal storage bin and the remaining gas with coal particulates continues to a baghouse where the coal fines are removed. The clean, inert but moisture laden gas is vented to the atmosphere and the coal fines are transported to the prepared coal storage bin. The prepared coal storage bin is sized to provide only surge capacity requirements for temporary operational problems such as pulverizer feeder trips. The 40-ton capacity of the prepared coal storage bin versus a much larger size will allow the bin to be more readily emptied during non-operation of the MHD power train, thereby reducing the potential for spontaneous combustion of the dried coal.

2.2.1.3 Injection

Injection of the coal into the MHD combustor will require a system pressure slightly above that of the combustor, i.e., approximately 6 atmospheres. A pressurized lock hopper system will provide a means to increase that delivery pressure to injection requirements. A continuous weigh system will be incorporated into this system to provide an accurate and repeatable method of introducing coal into the MHD power train. This will be accomplished by using stepped pressure transport vessels with inter-connecting lock hoppers. The necessary stepping pressure requirements in the transport vessels will be provided by the use of nitrogen. A separate air compressor will be required to provide pneumatic transport of the prepared coal to the MHD combustor.

2.2.2 Seed

The design requirements for the seed system are to provide adequate bulk storage of dry seed material, a means of maintaining that dryness and to consistently inject a specified amount into the combustor. To prevent problems that may be encountered with agglomerated particles a hammermill is needed to provide a uniform feed to a bulk weighing and transporting system.

Dry seed in the form of potassium carbonate (K_2CO_3) will be injected into the second stage of the combustor to provide adequate plasma conductivity in the channel for power production. This seed material will chemically combine with other elements in the plasma stream and will be removed in downstream sections of the HRSR or particulate control device. Seed reprocessing to recover the spent seed is not a part of the initial requirements of the ATS.

2.2.2.1 Storage and Delivery

The seed will be received by railcar and unloaded directly to bulk seed storage bins. As the ATS has an excess of dry nitrogen at its disposal, a slight nitrogen pressure will be kept on the bulk storage bin to combat the deliquescent nature of the seed. This will prevent agglomeration of seed particles into masses of wet lumps with the associated pluggage and handling problem. Feeders located at each seed storage bin will discharge to a hammermill to provide a uniform product for injection to the MHD power train. A screening system also will be employed at the discharge of the hammermill with screen oversize material being recycled into the hammermill. A pneumatic conveying system including a cyclone will be used to convey the seed to a lock hopper vessel and primary injector vessel. A continuous weighing system will be incorporated in the pneumatic/feed system to provide the required amount of seed. The transport air compressor will be used for both coal and seed transporting to the CFC. Figure 2-7 identifies the major equipment in the seed system. Table 2-8 summarizes the equipment capacities and flow requirements.

2.2.2.2 Seed Recovery

The successful introduction of the seed material into the plasma stream depends on several factors such as composition of the gas, seed material, coal ash composition, mass and heat transfer, particle mechanics, thermochemistry, and condensation phenomena. Since there is a high chemical

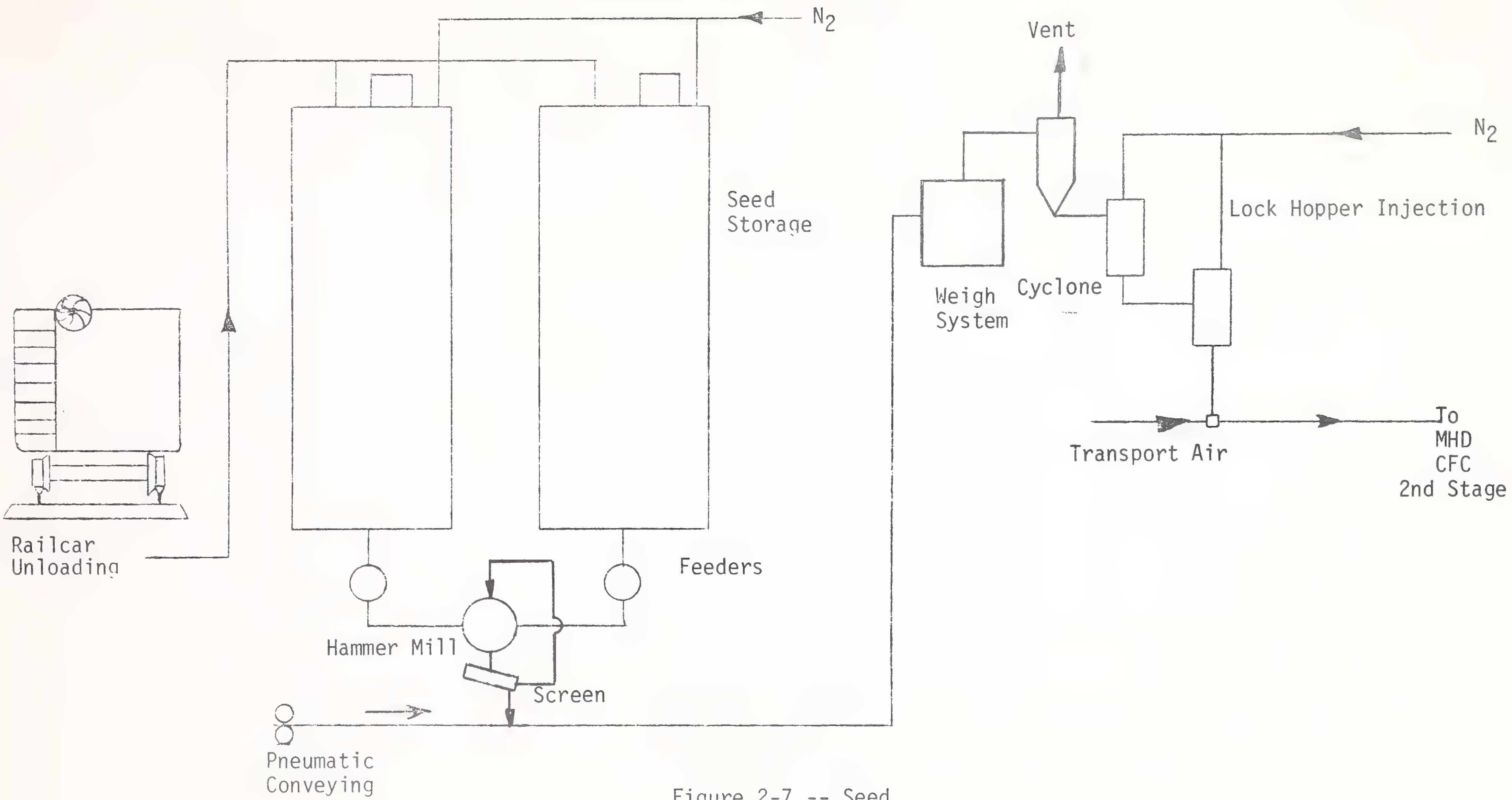


Figure 2-7 -- Seed

TABLE 2-8

SEED HANDLING

EQUIPMENT CAPACITIES AND FLOW REQUIREMENTS

Item	Quantity	Capacity (Each)	Nominal Operating Conditions
Rail Car Unloading	1	20 TPH	
Seed Storage Bin	2	500 Ton	
Feeders	2	5 TPH	3.93 TPH (0.9916 kg/s)
Hammermill	1	5 TPH	3.93 TPH (0.9916 kg/s)
Injection System	1	5 TPH	3.93 TPH (0.9916 kg/s)

affinity of potassium to sulfur, the seed material will combine with the free sulfur in the combustion gases to produce K_2SO_4 thereby providing an effective method of in situ sulfur dioxide (SO_2) control.

The K_2CO_3 seed will be injected into the second stage of the combustor to prevent loss of seed in the combustor slag. Seed material will be recovered in the secondary portion of the heat recovery furnace by condensation prior to reaching the closely spaced tube sections. Collection hoppers and discharge mechanisms are appropriately located in areas of the furnace to enable bulk collection of material that is heavily laden with potassium (primarily K_2SO_4). The remainder of the collected material is fly ash with constituents related to the chemical composition of the coal.

2.2.2.3 Recovered Seed Disposition

The ultimate objective of this retrofit study is to demonstrate the integration of MHD and bottoming cycle components as well as to demonstrate the Advanced Test System in an integrated utility setting; therefore, this section only addresses the recovery of potassium-bearing bottom ash and fly ash. Seed reprocessing of the bottom ash and fly ash is not considered mandatory to the ATS operation because reprocessing would complicate startup and test operation of the facility. Seed reprocessing is a essential part of the MHD design concept and must be included at some time in the overall technology and promotion of MHD. Various schemes have been promoted, studied, and described at length in several studies; however, because there is no existing operational plant, some technical risk would be involved in the construction and operation of the plant when it is included with the ATS. Another factor is the expected intermittent operation of the ATS, this

mode of operation does not warrent an immediate large investment in a processing plant as part of the ATS. Therefore, material recovery and disposition is only considered in this engineering assessment.

It is anticipated that the potassium-bearing material that would be economical to reprocess will be stored for reprocessing at a plant that would be designed, constructed, and operated at some later date. Slag, bottom, ash and fly ash that are not economically feasible for further processing will be sold or disposed in a environmentally safe manner. A consideration may be made to sell the potassium-related material as a fertilizer product.

The seed reprocessing plant is a future consideration once the ATS facility is continuously and consistently operating. Recovered seed material would be transported to the reprocessing plant where it would be chemically reprocessed to a potassium compound and then returned to the MHD facility bulk seed storage silos. Future MHD installations very likely will have a separate off-site seed reprocessing plant operated independently of the utility.

2.2.3 Oxidant

The oxidant supply system provides oxygen enriched pressurized air to the MHD power train preheating system at the pressure and oxygen concentration specified. The present specifications are 366,355 lbm/hr (46.16 kg/sec) at 36 mole % oxygen with an injection pressure of 6 atmospheres. Figure 2-8 is a block diagram illustrating the basic oxidant supply system. The major components of the system are the air separation unit (ASU), oxidant mixing system, and power supply.

2.2.3.1 Air Separation Unit

Two companies were contacted for process recommendations to produce the oxidant supply required. Each was requested to design for the best economics, considering plant cost and energy consumption, coordinately with reliability of operation and minimizing redundancy.

Other requirements for the ASU are:

- Additional production of 10 TPD of liquid oxygen for tank storage of 20,000 gallon capacity to compensate for minor ASU maintenance shutdowns.
- Additional production of 10 TPD of liquid nitrogen for tank storage of 20,000 gallon capacity for use with the superconducting magnet refrigeration system.

Gaseous nitrogen is available at atmospheric pressure as a secondary product of the ASU. This gaseous nitrogen will be preheated in the back passes of the HRSR for further usage as a tempering medium in coal drying, dry makeup gas for the seed sytem, and as an inerting gas, as required.

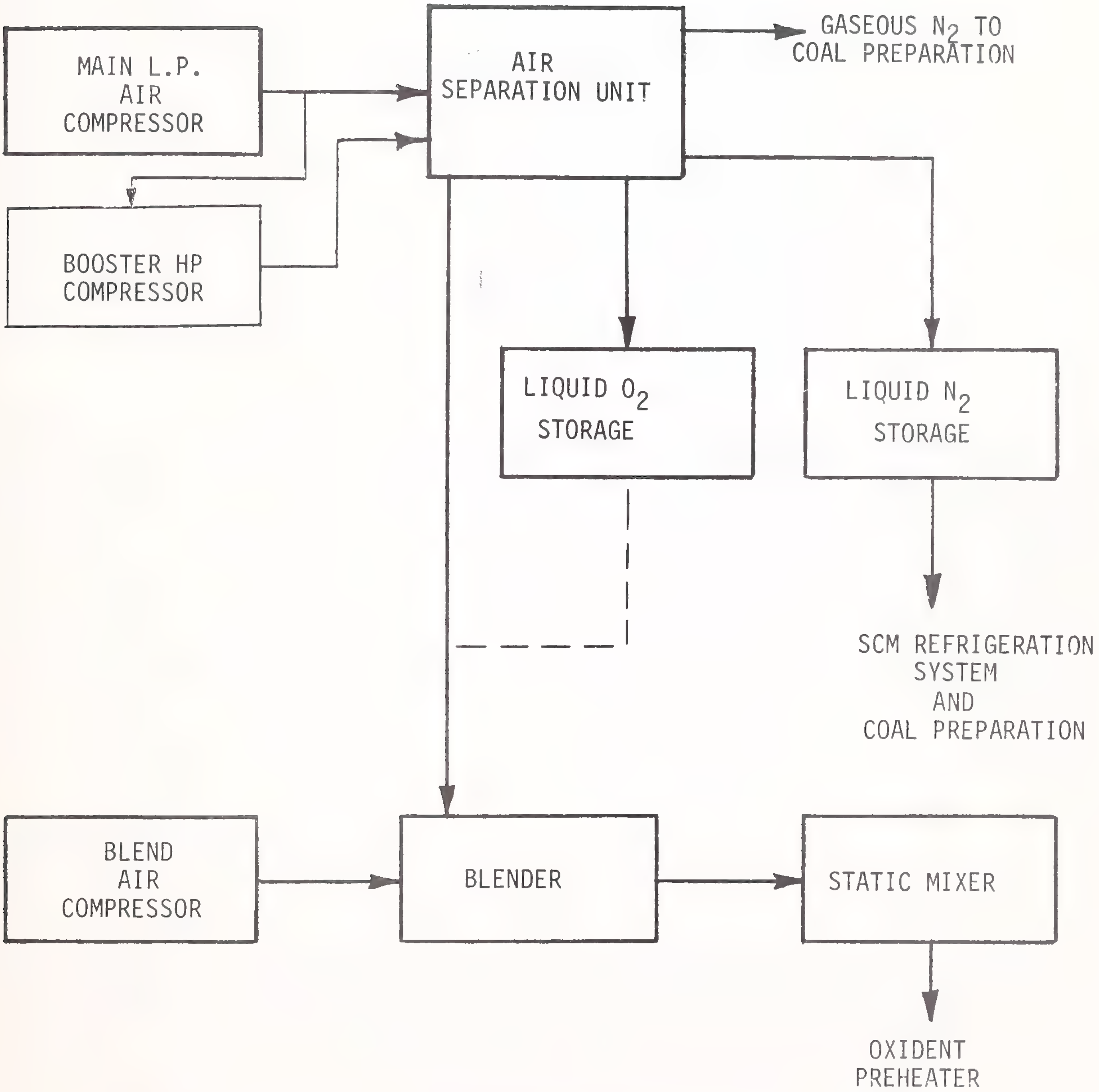


Figure 2-8 -- Oxidant Supply and Air Separation

Figure 2-9 illustrates one of the suppliers state-of-the-art process including pressurizing the product oxygen by pumping the liquid phase and vaporizing the liquid at pressure. The use of liquid phase pressurization produces the oxidant with the lowest overall specific energy. Liquid phase pressurizing pumps have been used in this country since the late 1930's on small air separation plants. During World War II hundreds of small plants were constructed employing reciprocating liquid pumps to fill aviator breathing oxygen cylinders. Beginning in the 1940's, centrifugal liquid oxygen pumps were employed on large tonnage oxygen plants. Reliability has been demonstrated to be at least equal to that of gas phase compression and reduced energy and capital costs have been achieved. Overall energy reduction is about 10%.

The air separation process as proposed by the second supplier and shown in Figure 2-10 differs from conventional plants in this country in that the oxygen is compressed outside the process plant. The gaseous oxygen is then mixed and compressed with the air in the oxidant compressor. This process approach has been the dominant design employed outside the United States and has a long history of reliability.

2.2.3.2 Oxidant Mixing System

Prior experience in continuous fluid mixing indicates that the best results are achieved by producing a uniform blend prior to entering the mixing chamber.

Records of fluid concentration mixed continuously exhibit a sine-curve pattern. While the average concentration is achieved, regardless of the

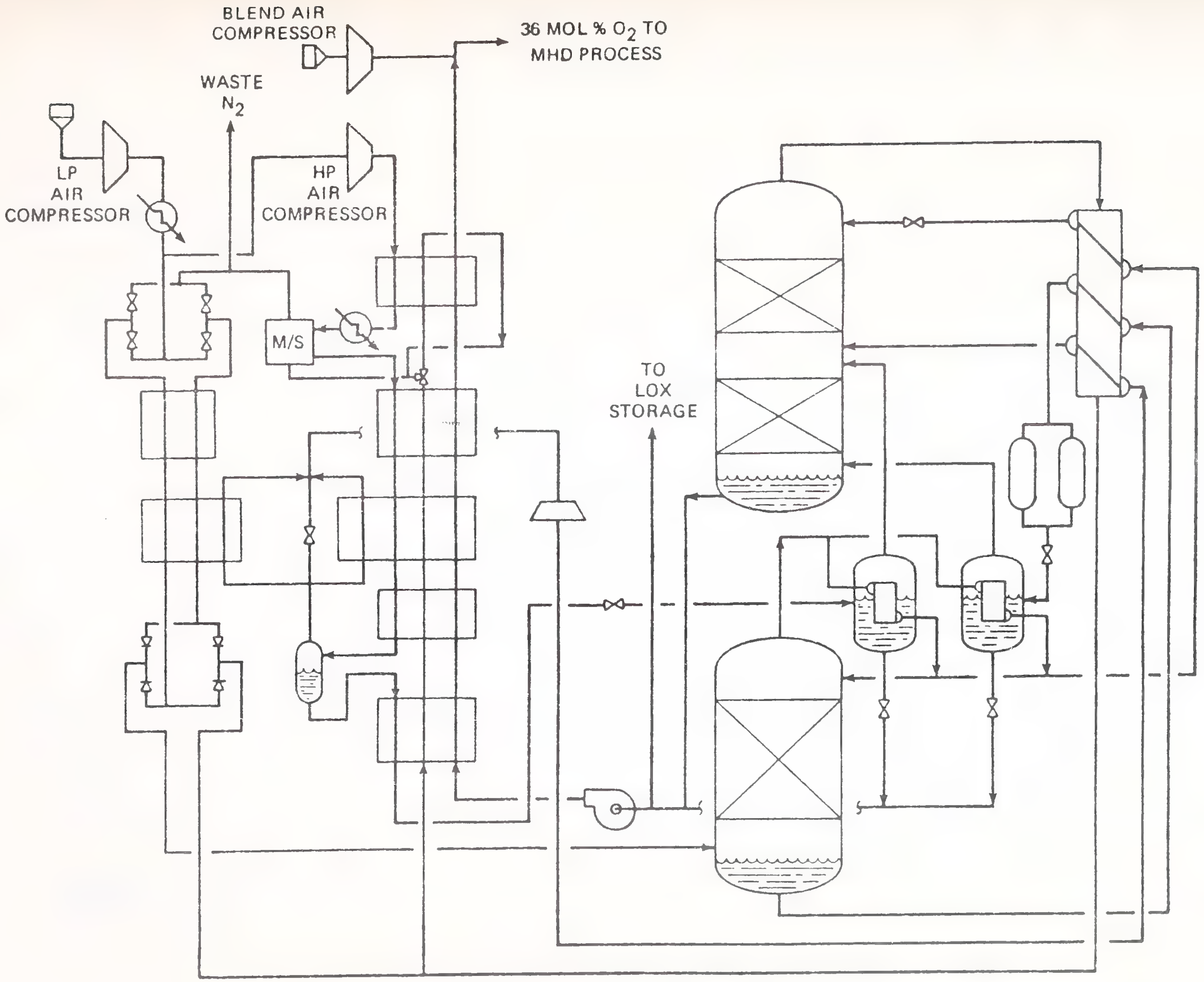


Figure 2-9 -- Oxidant Supply System - Typical Plant (Air Products)

Patented process of: Air Products & Chemicals, Inc.
Allentown, PA

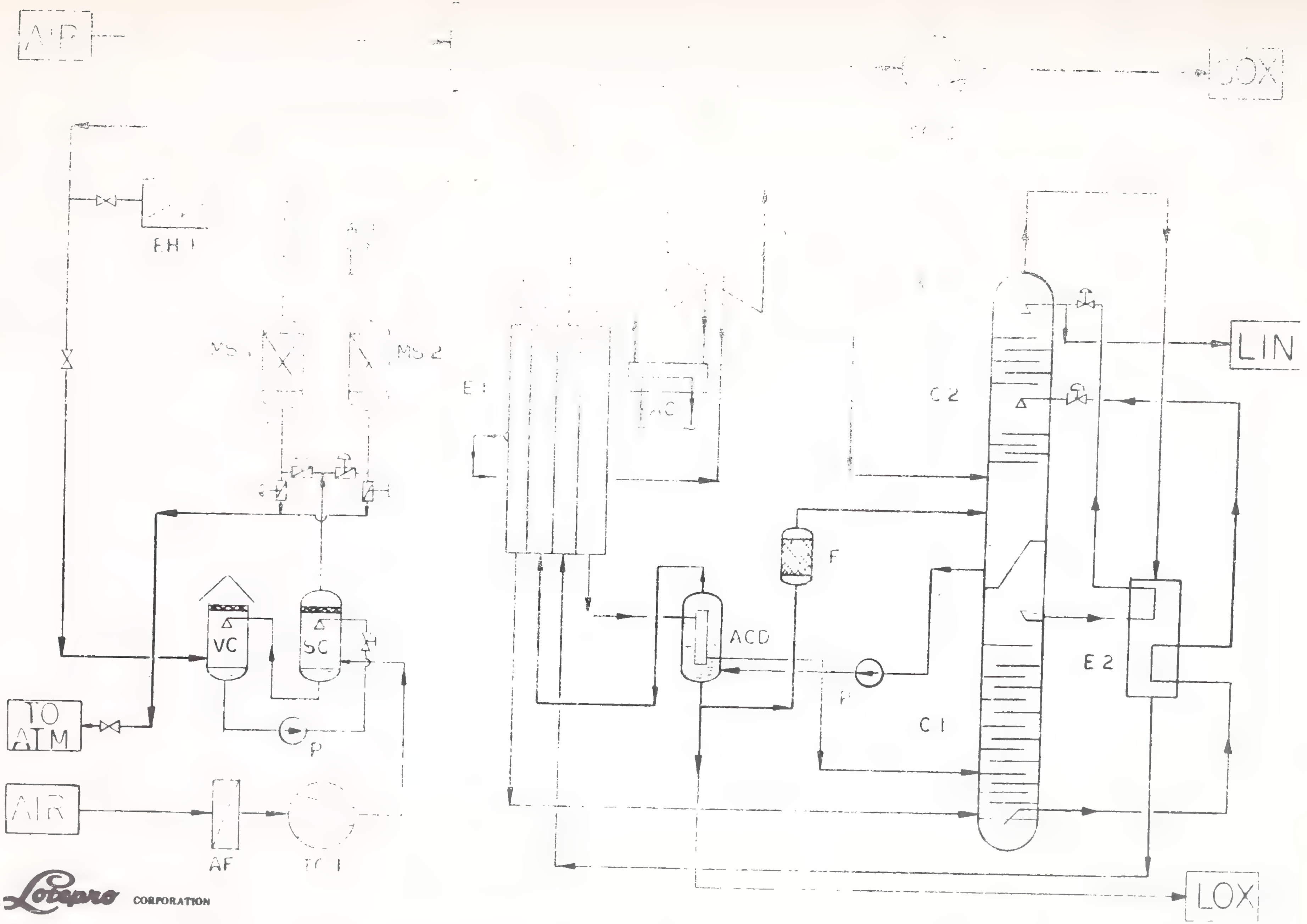


Figure 2-10 -- Oxidant Supply System - Typical Plant (Lotepro)

blending device, the amplitude of the "sine-curve" can be deleteriously large and affect the combustion characteristics. Blending with a simple piping-tee will produce the largest amplitude, while blending with a "Y" pipe fitting will be somewhat better.

The amplitude approaches a staight line when producing a blend with a vena-contracta section and that method is recommended to produce the oxidant mixture. The oxygen from the ASU is introduced at the low pressure point of the vena-contracta. An inline static mixer is then used to complete the mixing of the oxidant. The pressure drop for complete mixing is only about 1 psi.

2.2.3.3 Power Supply

Electrically-driven compressors provide an ease of operation that greatly simplifies the total plant startup and operation as compared to steam turbine driven. Also steam driven would require obtaining the steam from the power plant thereby adding undesirable complexity to the steam system. Electrical power for the air compressors, therefore, was selected as the most reliable and least complex. Adequate power is available from the adjacent substation. Steam turbine drives could have had major impacts upon the existing turbine condensing and feedwater system. Three separate integral gear (four-poster) type compressors with two intercooled stages as shown in Figure 2-9 would be used to reduce shaft horsepower requirements. Those shaft horsepower requirements would be about 25000 BHP to provide an oxidant temperature of about 270°F.

It would be possible to recover more of the heat of compression into the oxidant product stream. However, it is anticipated that this would increase the compressor shaft power requirements by about 4000 BHP and require non-standard, more expensive compressors. It is doubtful that the additional 200 to 300°F of oxidant temperature could justify this extra compression cost, for a plant of this size.

2.2.4 Effluent Handling

Ash and seed effluents are divided into three groups depending on the relative amounts of ash and seed in each stream as shown in Figure 2-11. The slag from the combustor will be collected in water quench tanks, dewatered and transported to a landfill or used for filler and building material. It is anticipated that this material will be classified as non-hazardous with 29,190 tons generated during an operating year of 7,000 hours, as shown in Figure 2-11.

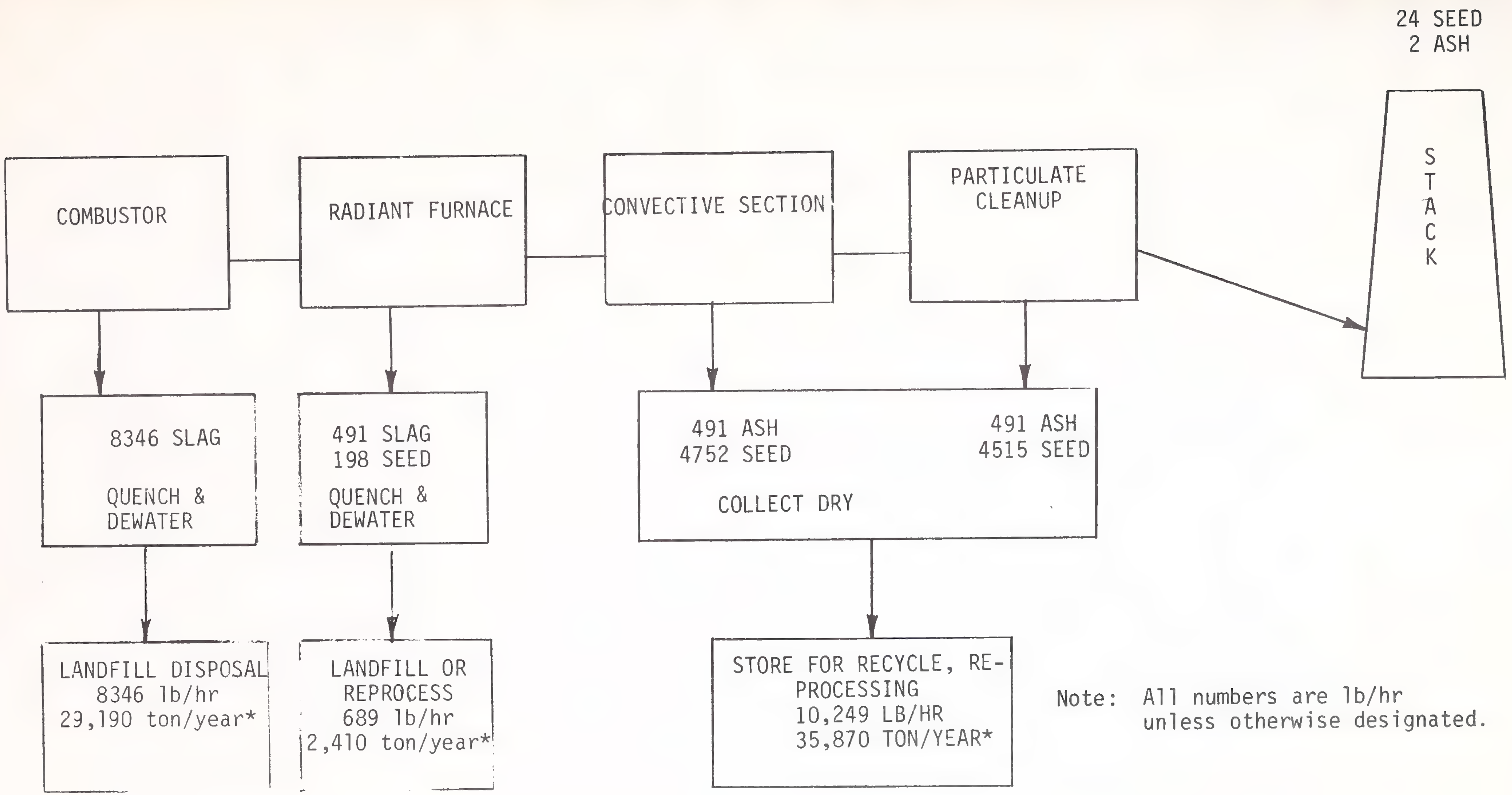
Bottom ash from the radiant furnace may require quenching and dewatering separately from the combustor slag. Depending on the chemical and physical form of the seed material in this waste stream, it may require treatment to recover soluble potassium salts before disposal of the slag. If the seed is combined in the slag matrix in such a manner that subsequent testing shows it to be non-hazardous (as defined by Resource Conservation and Recovery Act) then these wastes can be handled in the same manner as combustor slag.

Seed and ash materials from both the convective section and the particulate control device will be collected dry (or possibly wet in some sections) and transported off site for future reprocessing. These streams represent collection of the remaining seed material. For any long-term operation, it will be necessary to reprocess seed material from both operational economics and waste disposal viewpoints. Even if economically feasible, land disposal would not be allowed for the water soluble potassium compounds. During operation nearly five tons per hour of potassium salts will be collected. A sealed storage facility sufficient to handle the spent seed at the rates indicated in Figure 2-11 will be required. One year's storage will require about 25 acre feet (equivalent to five acres, five feet deep). Nearly an equivalent amount of landfill must be available for disposal of slag.

The waste water flows from the ATS will be recycled to the extent that is practical prior to routing to the water treatment plant. The processed water from the water treatment plant will either be recycled or discharged to the Yellowstone River. Storage capacity will be included in the water treatment plant to maximize the recycling opportunities.

2.2.5 Auxiliaries

Auxiliary systems are those MHD support systems that have a direct or secondary interface with the MHD power train or its support equipment. This section deals with water systems that are an integral part of the ATS, and with auxiliary fuels, compressed air and HVAC requirements.



Note: All numbers are lb/hr unless otherwise designated.

Figure 2-11 -- Ash and Seed/Waste Recycle Streams

*Based on 7,000 hours of Operation

2.2.5.1 Feedwater

The HRSR requires feedwater of a similar quality to that used at the Corette plant to ensure protection of the heating surfaces and provide adequate steam quality. Methods to ensure adequate delivery of that feedwater under initial startup and normal operating conditions is required as well as providing the necessary subsystem for proper chemical control. The ATS will share the evaporator, condensate and feedwater system that is currently in use at the Corette plant. The interconnecting tie will be after the No. 5 feedwater heater. A booster feedwater pump will be required to overcome the additional pipeline friction losses due to the more remote location of the HRSR. There are also additional friction losses in the first stage CFC and MHD diffuser cooling loops and in the recirculation loops during startup operation.

The HRSR boiler fill and wash pump will also have its water supplied from a condensate storage tank with makeup from the Corette condensate system. It will have an interchangeable spool to provide a second water source from the city water supply. A wash water circulating pump is included to provide adequate cleaning action for the various boiler headers during maintenance.

The desuperheaters on the superheated and cold reheat steam receive their water supply directly from the booster feedwater pump to adequately control final steam temperatures with a high quality water supply.

To provide adequate chemical control of the HRSR boiler water a chemical feed system is required. The pump/makedown tank system will be similar to the existing units at Corette. To maintain proper water and steam chemistry,

additions of phosphate, caustic, oxygen scavenger, and neutralizing amines are anticipated. A water sampling system would also be included as a means of analyzing the various parameters on feedwater, steam, and continuous blowdown. A blowdown control system will also be included as part of the sampling system. Figure 2-12 identifies the major components of the feedwater system.

2.2.5.2 MHD Channel Cooling Water

All interconnections between the MHD power train must be electrically isolated from support structures, piping, building steel, etc., due to the high electrical field generated around the combustor second stage and the MHD channel. The closed circulating cooling water loop for cooling of the combustor second stage and the MHD channel is within this highly charged field and will use condensate for electrical isolation. The cooling water will dissipate its heat to the atmosphere via a circulating pump and water cooling radiator system. A mixed bed demineralizer will be continuously used as a slip stream to retain the required water quality. Makeup water will be provided from the condensate storage tank. Figure 2-13 shows the major components of the system.

2.2.5.3 Inverter Cooling Water

The inverter will require cooling water to dissipate the thyristor heat load. A closed cooling water loop with circulating pump, and water cooling radiator will be used to dissipate this low grade heat to the atmosphere instead of adding to the heat load being rejected to the Yellowstone River.

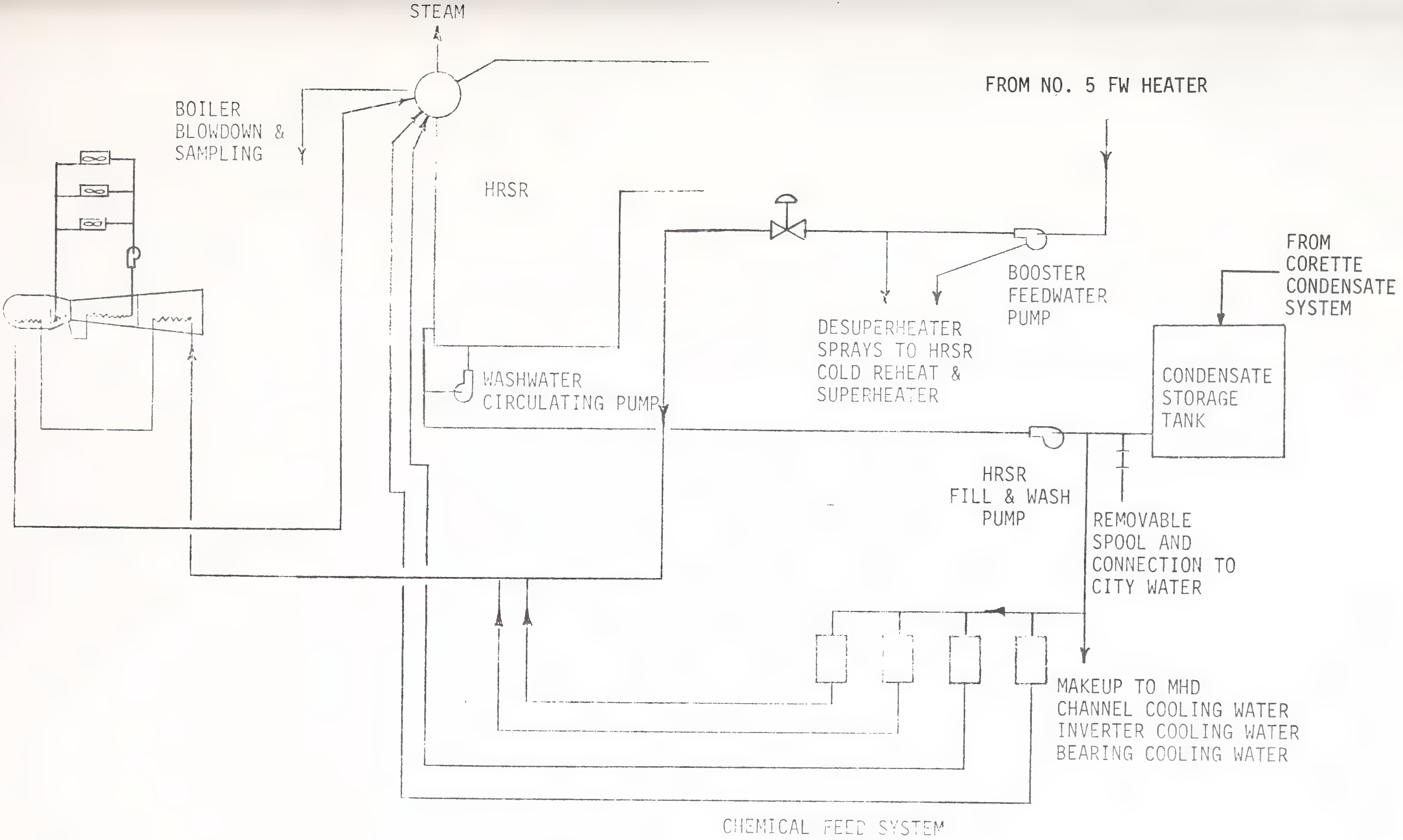


Figure 2-12 -- Feedwater

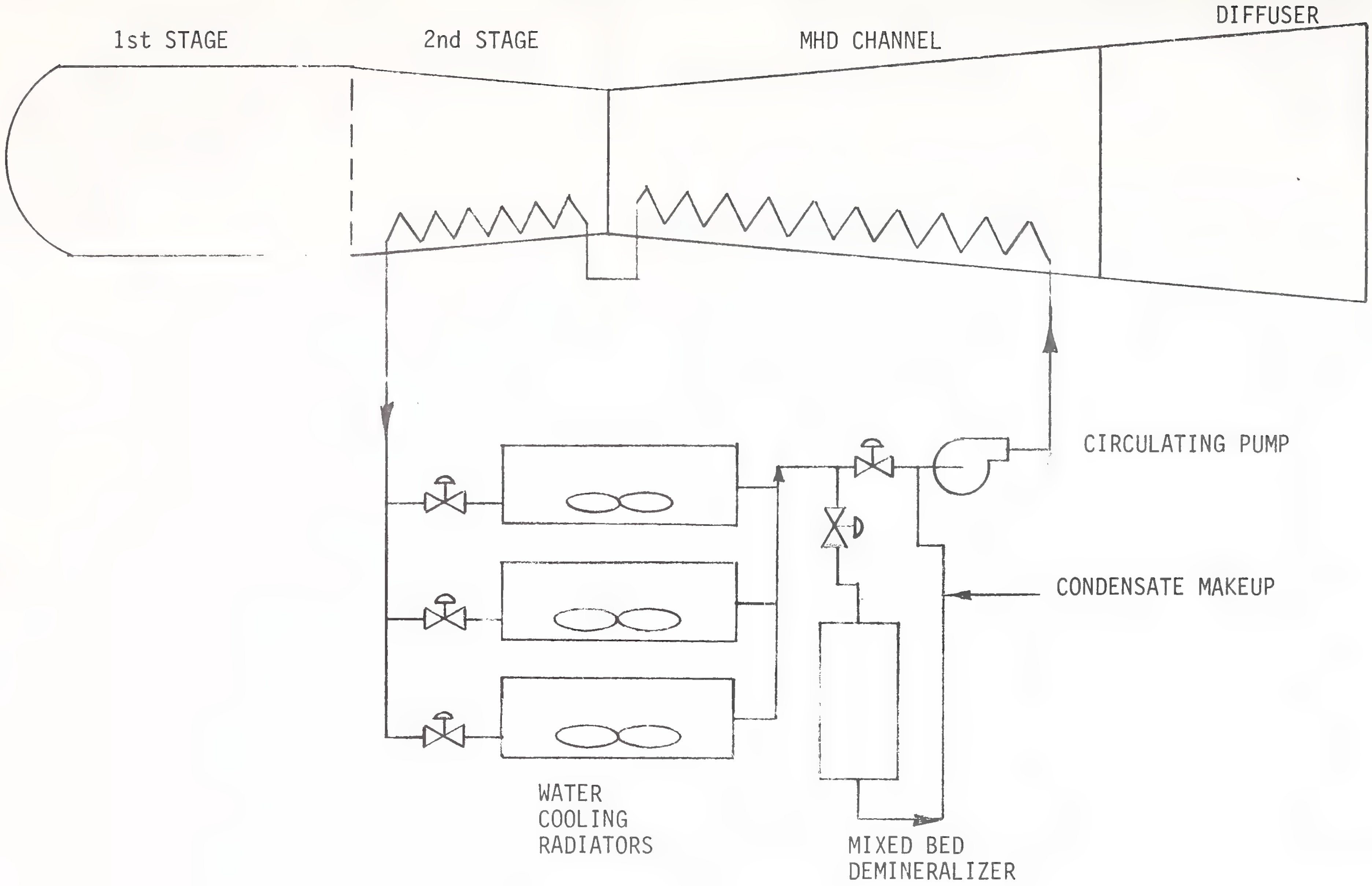


Figure 2-13 -- Channel Cooling Water

Makeup will be from the condensate storage tank to assure water quality and minimize corrosion, scaling, and makeup requirements. Figure 2-14 identifies the major components of this system.

2.2.5.4 Service Water

A primary cooling water system utilizing Yellowstone River water is required to dissipate heat loads generated from mechanical equipment and lubrication oils. This system should be similar to the existing Corette plant circulating, service water, and screen wash system to provide a continuity of operations between the two plants. The existing Corette system will continue to supply the condenser cooling water for the turbine-generator and the Corette plant heating loads. The use of any existing intake structures on the Yellowstone River would reduce construction costs and simplify site layout.

A new service water pump will be installed at the Corette plant intake structure. This will take advantage of an available area on the existing intake structure at that location. The pump will provide the cooling water supply to the high efficiency plate type heat exchangers used for bearing cooling, after which the service water will discharge through the existing Corette discharge structure. This discharge will have to be within the discharge flow and temperature requirements currently in effect at the plant and total flow must also not restrict the current Corette plant cooling requirements.

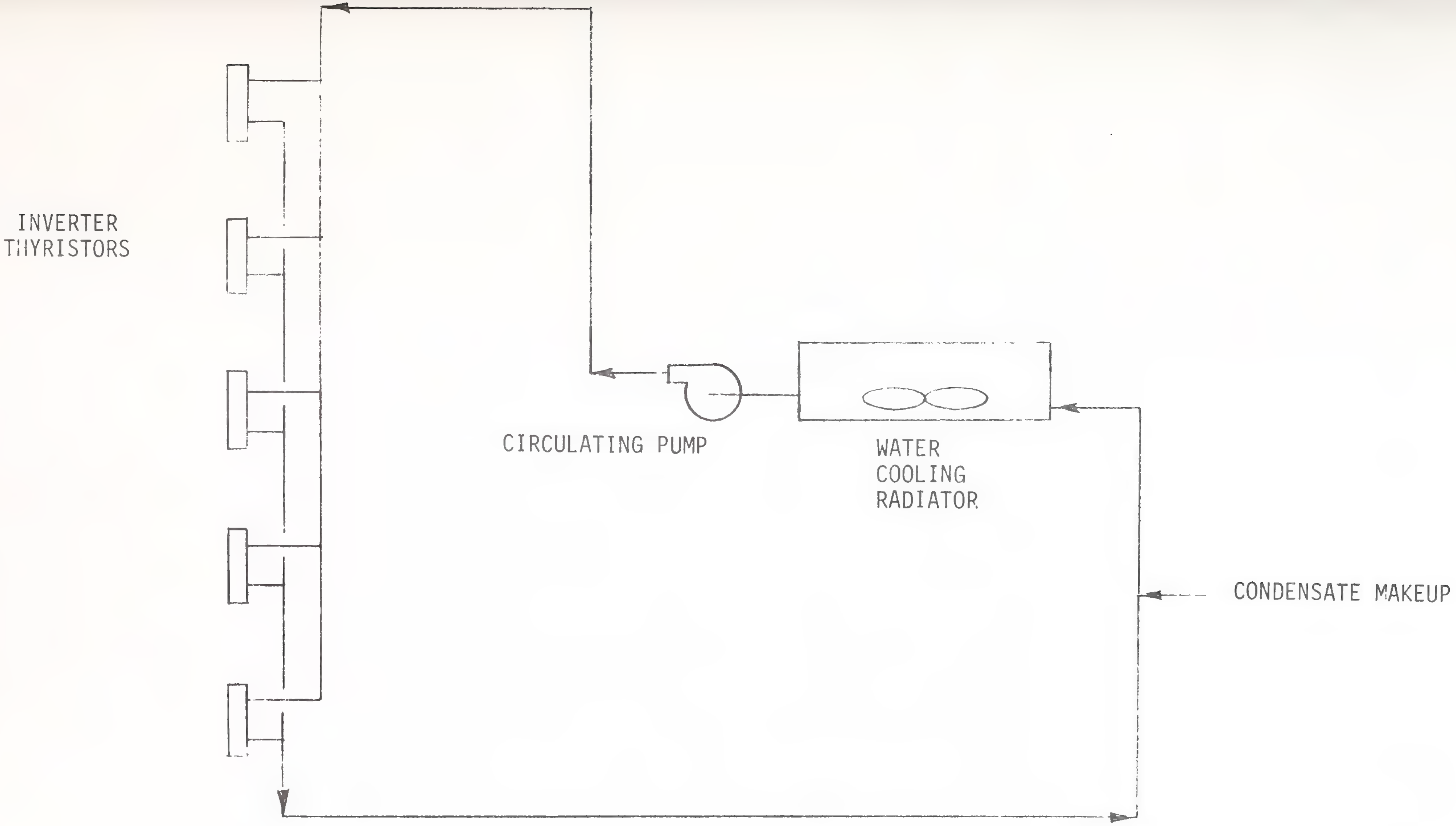


Figure 2-14 -- Inverter Cooling Water

Makeup water requirements for the CFC slag handling system, HRSR bottom ash sluicing system, and the blow-off quench tank will come from this system as well as any requirements for floor wash down hoses. Figure 2-15 identifies the service water system components.

2.2.5.5 Bearing Cooling Water

A system will be required to provide a cooling water medium to offset heat loads generated from various mechanical equipment and their lubrication oils. The system should be similar to the existing Corette bearing cooling water system and provide cooling functions to similar items of equipment.

The bearing cooling water system will circulate water through the high efficiency plate type heat exchangers to serve a similar function as the existing bearing cooling water system. This bearing cooling water system will be capable of handling the cooling requirements on major equipment. That equipment would be items such as the feedwater booster pump, pulverizers, helium refrigerant compressor, service air compressor jacket and aftercoolers, air dryer cooler, SCM subsystems, slag/ash grinder, injection air compressor, blend air compressor, main L.P. air compressor, and the booster H.P. air compressor. Small systems requiring some recirculating cooling water such as sample coolers, instrument racks, etc., would also be on this system. Makeup will be from the condensate storage tank. Figure 2-16 identifies major components of the system and summarizes the usages.

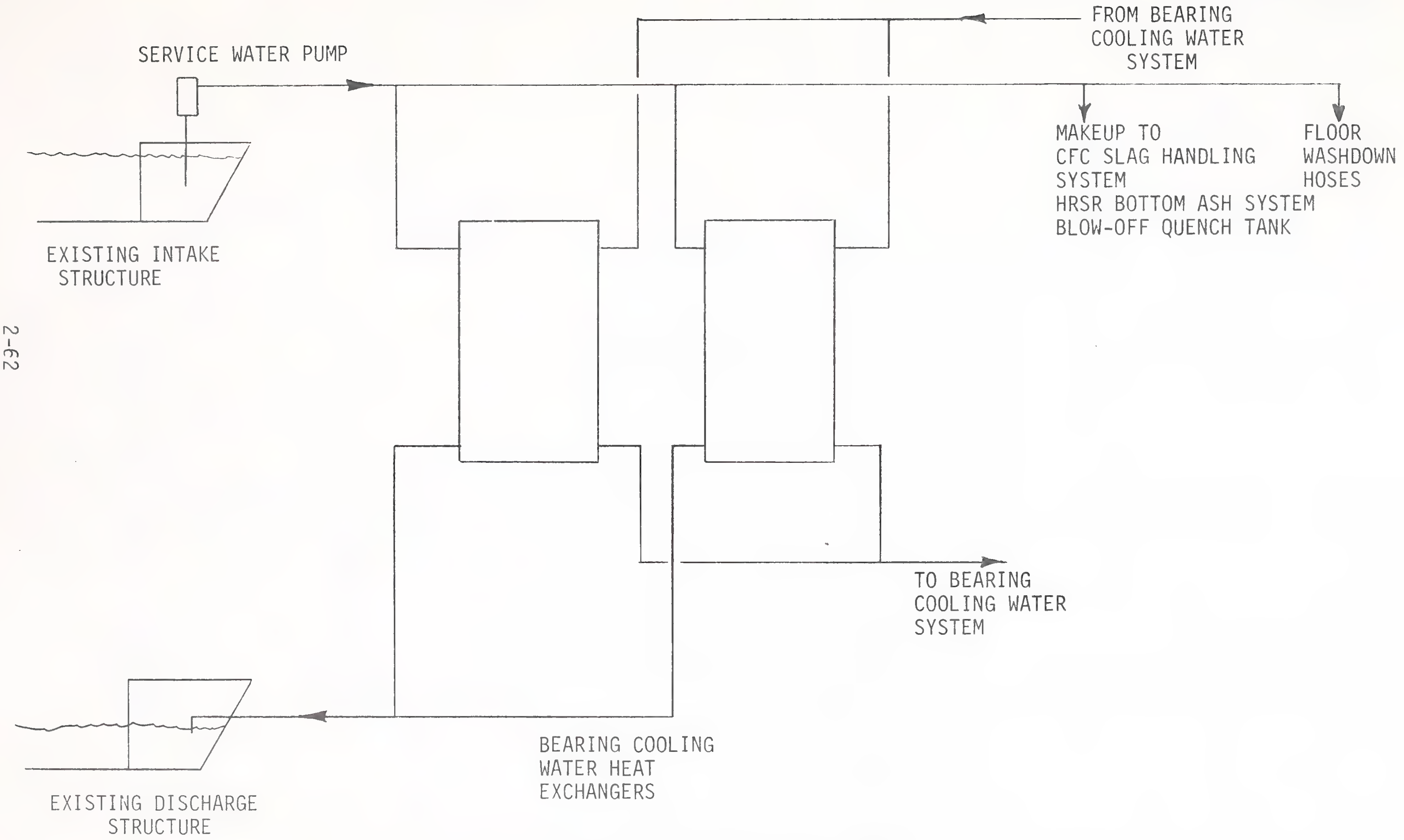

SERVICE WATER PUMP
EXISTING INTAKE STRUCTURE
FROM BEARING COOLING WATER SYSTEM
MAKEUP TO
CFC SLAG HANDLING SYSTEM
HRSR BOTTOM ASH SYSTEM
BLOW-OFF QUENCH TANK
FLOOR WASHDOWN HOSES
TO BEARING COOLING WATER SYSTEM
EXISTING DISCHARGE STRUCTURE
BEARING COOLING WATER HEAT EXCHANGERS

Figure 2-15 -- Service Water

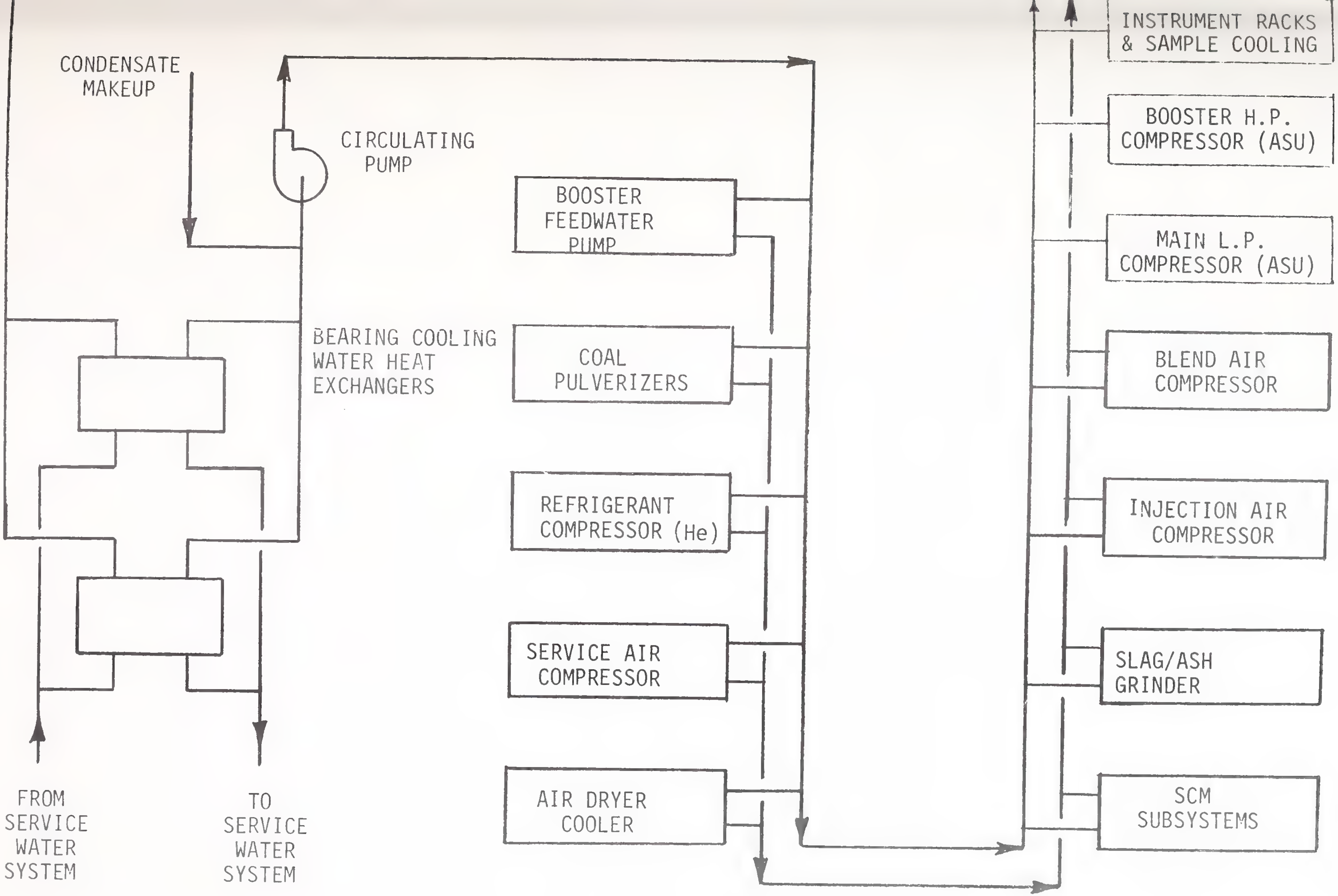


Figure 2-16 -- Bearing Cooling Water

2.2.5.6 Potable Water

A potable water supply is required for personnel use in the plant as well as a clean source of pump gland seal water. Pumps shall utilize mechanical seals as far as practical in the entire ATS facility to reduce water consumption.

A potable water system break tank will be installed to provide potable water with a consistent head to the locker room, electric water coolers, pump gland seal water, and for inductor water to the oxygen/combustor analyzer. Analysis of the existing system is required to determine quantity and availability of the existing city water supply. A secondary water supply to the HRSR fill and wash pump can be obtained from the city water line by using an interchangeable spool from the normal condensate supply line. City water will be routed to the elevated break tank from the existing city water main. A meter will be included to determine the usage of the water source. Figure 2-17 provides an outline of the system and the water uses.

2.2.5.7 Fire Protection

Adequate fire protection is not only a requirement per regulatory agencies but also for plant insurance considerations. Design calculations will be required to ensure that the existing plant-wide fire system can be expanded to include fire loop perimeters around the new buildings and also provide sprinkler coverage inside as required by the National Fire Protection Association (NFPA). Fire extinguishers will be located at the appropriate locations in the facility. Figure 2-18 outlines a modified system to include the ATS.

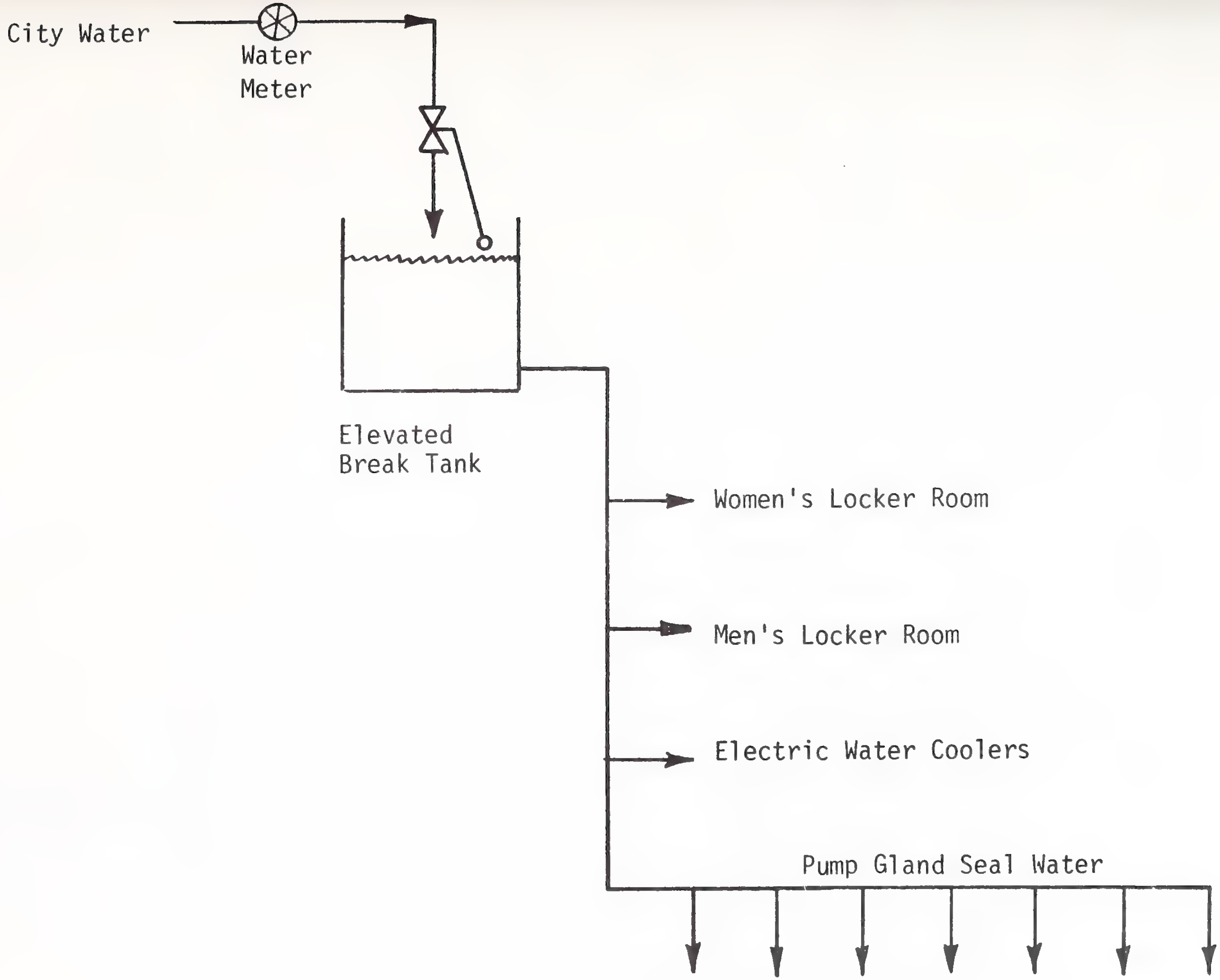


Figure 2-17 -- Potable Water

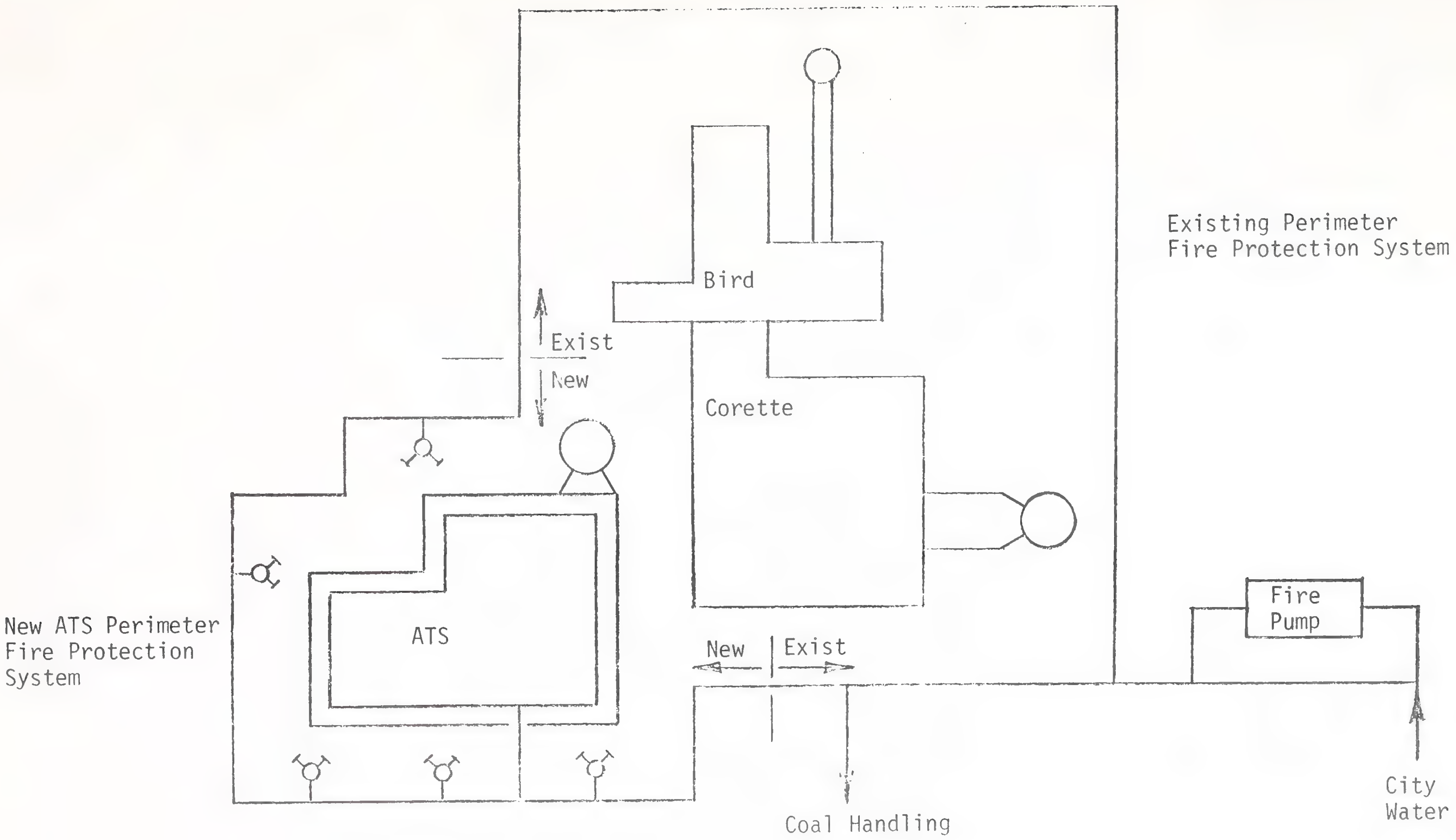


Figure 2-18 -- Fire Protection

2.2.5.8 Natural Gas

There is a fuel requirement for pilot ignition of coal in the coal predryer, pulverizer airheater and coal fired combustor at the ATS. In addition to that nominal requirement of fuel, the assumption was made that firing of an alternate fuel in the HRSR may be required for various operational modes.

The fuel requirement for pilot ignition of the coal predryer, pulverizer airheater, coal-fired combustor and the potential firing of the HRSR during periods of non-MHD operation will be satisfied from the existing natural gas supply at the Corette plant site. Usage of natural gas is minimal with pilot ignition during startup times and virtually non-existent in normal operation. The use of warmup guns to bring the HRSR above ambient conditions during startup and before introduction of hot MHD plasma gases is anticipated. The provision for alternative firing of the HRSR is offered as an operational means to overcome abnormal conditions during shutdown, startup, and furnace recovery times. Figure 2-19 identifies the existing gas service and the new requirements.

2.2.5.9 Air Compressor

A reliable source of plant service air will be required for general duties throughout the plant as well as some clean dry air for specific instrument requirements.

An analysis of total air requirements should be completed to assess whether one or two air compressors are needed. If instrument action is primarily

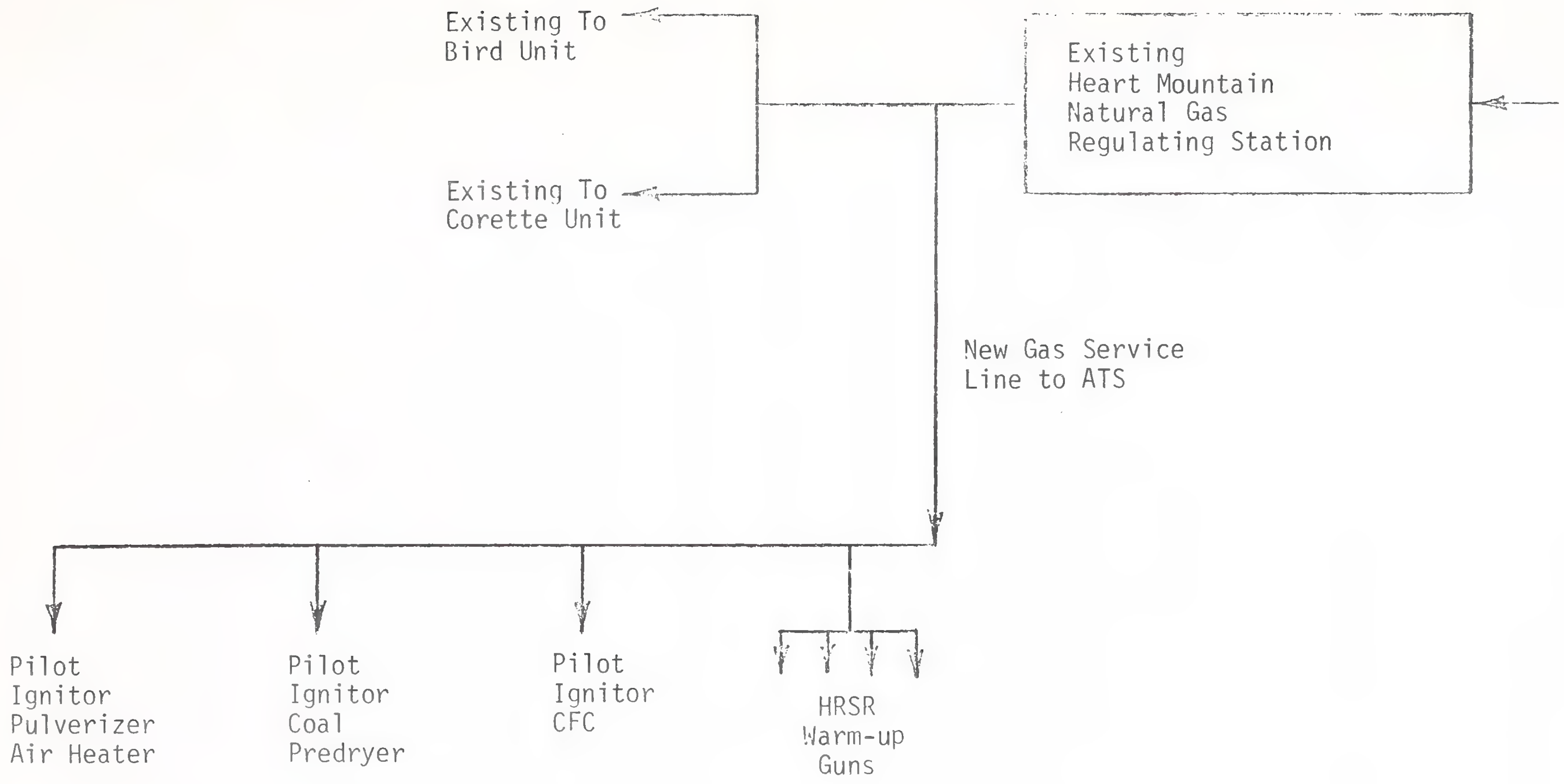


Figure 2-19 -- Natural Gas

electrically driven, soot blowers steam driven, and other air usage minimized, there would be minimal requirements for plant air usage and a single low-volume air compressor may be satisfactory.

A centrifugal type service and instrument air compressor will provide the quantities of service air during operation of the facility. A slip stream from the centrifugal air compressor or compressors will be routed through an air dryer to supply the moderate amounts of clean dry instrument air.

An injection air compressor is also required to provide the transport air for the prepared coal and seed injection systems. A centrifugal air compressor separate from the plant service and instrument air system will be used for this service. Figure 2-20 identifies the major components of the compressor system.

2.2.5.10 Heating, Ventilating and Air Conditioning

All of the plant building areas will require some method of heating, ventilating, or air conditioning per code and health requirements. Fresh air makeup, comfortable working conditions, temperature/humidity controlled environments, and freeze protection are prerequisites for the various heating and ventilating systems. An extension of the existing Corette 175 psig steam system will be used for the heating medium if that system is found to be adequate in size to supply both the existing plant and the new ATS facility. An alternate design would use electric resistance heating or possibly utilize the low-grade heat source from the channel and inverter cooling systems with

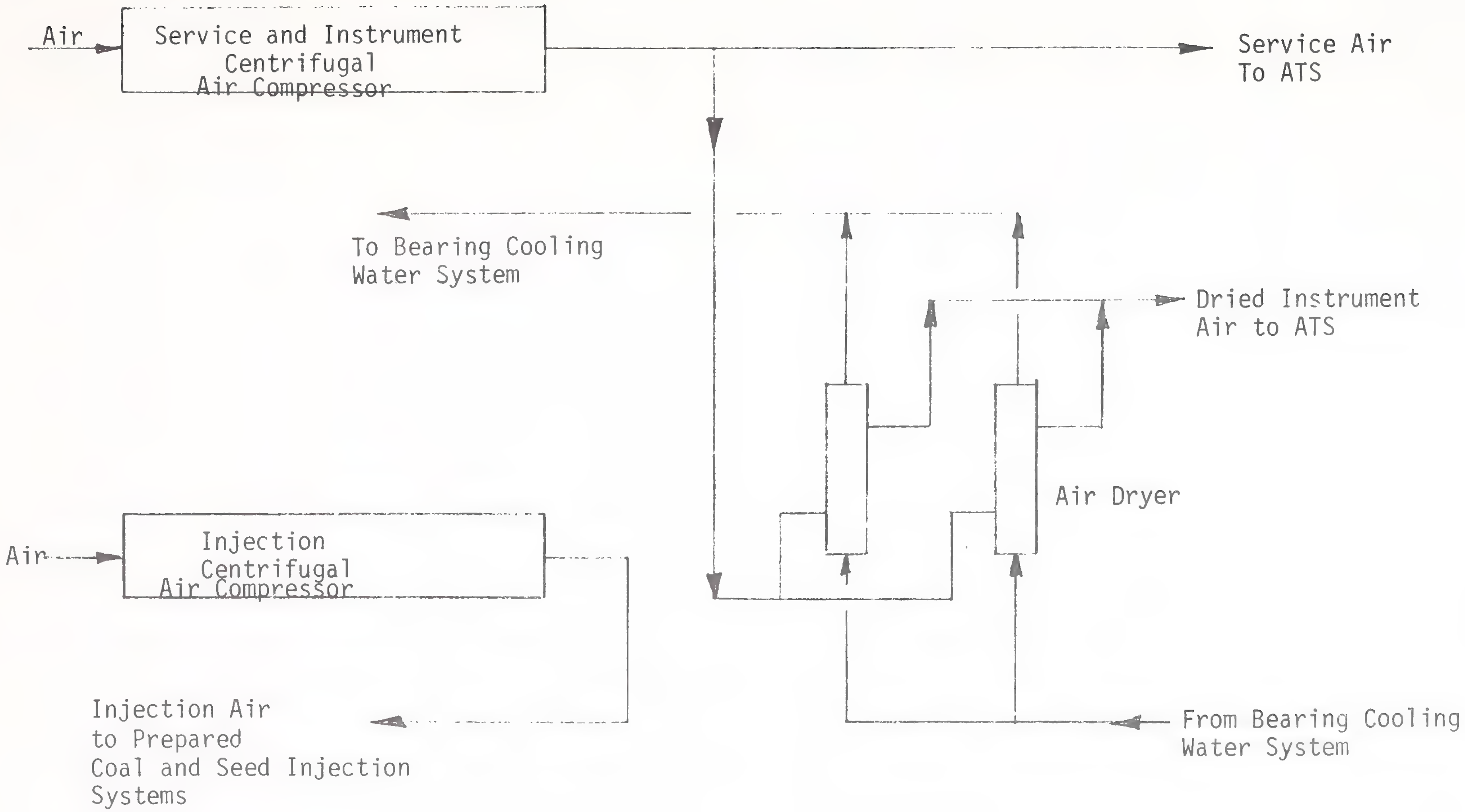

Air
Service and Instrument Centrifugal Air Compressor
Service Air To ATS
To Bearing Cooling Water System
Dried Instrument Air to ATS
Air Dryer
Air
Injection Centrifugal Air Compressor
Injection Air to Prepared Coal and Seed Injection Systems
From Bearing Cooling Water System

Figure 2-20 -- Service and Instrument Air

a back-up auxiliary hot water heating boiler. Additional cooling and humidity controlled environments will be used in sensitive areas such as the control room, instrument room and the adjacent data acquisition system.

2.2.6 Particulate Control

The particulate control device is dictated by requirements for best available control technology (BACT) or lowest achievable emission rates (LAER) depending on specific permit requirements described in Section 3.2. For all practical purposes there is currently little difference between these two designations. BACT, LAER and the assumptions and uncertainties inherent in MHD combustion favor the selection of fabric filtration to achieve high collection efficiency over a possible wide range of particle size distributions.

One operating constraint is that temperatures must generally be controlled below 500°F for commonly used bag filter media. The plant material balance shows the collected particulates at this point in the process will be primarily potassium compounds since most of the ash is removed as slag at the combustor or the radiant furnace. This material will be collected dry and handled as described in Section 2.2.4.

A mimimum collection efficiency of 99.5% is required at the design collection rate of 5,000 lbm/hr. For design purposes, a 99.9% collection efficiency at 10,000 lbm/hr should be considered to allow for significant increases in ash or seed carryover from the upstream process. A trade-off between cost and acceptable pressure drop and air/cloth ratio will be an integral part of the

size selection process. A unit divided into separate sections sized so that operations could continue with one section out of service would also be desirable from a maintenance and reliability viewpoint.

2.2.7 Substation and Transmission

The 25 KV AC output from the inverter will pass through a protective circuit breaker and be carried on underground cables capable of carrying 30 MW of power. The cables will feed the main transformer to step the voltage up to 100 KV to be compatible with the MPC's system at the nearby Billings Steam Plant Substation. This will require a 100 KV transmission line approximately 600 ft in length and a protective circuit breaker where the transmission line meets the 100 KV station ring-bus. There will also be auxiliary transformers to serve the major 13.8 KV motor loads, other facility electric requirements, and miscellaneous lighting. Figure 2-21 is a one-line diagram of the system.

The inverter output will pass through a 25 KV Sulphur Hexafluoride Gas (SF6) circuit breaker rated at 1200 amperes. This breaker will be located in the inverter building. From this breaker the output will be carried on three, size 1000 MCM, shielded 25 KV copper cables underground in six-inch PVC conduit encased in concrete. A copper equipment grounding conductor (size 4/0) associated with this circuit will be solidly tied to the station ground mat and carried outside the six-inch duct and tied to the body of the pothead where the cables terminate. Suitable valve type lightening arrestors will be installed adjacent to the pothead and will use the ground at the pothead. The cables will rise up in six-inch galvanized rigid conduit at the substation, located about 75 ft northwest of the northwest corner of the Corette steam plant.

The steel substation will provide a 25 KV aluminum bus rated at 1200 amperes and a 13.8 KV bus rated at 1200 amperes. The 25 KV bus will be fed by the underground cables through 1200 ampere hook operated disconnects.

The main transformer rated 25/33/42 MVA-OA/FA/FOA -- 25 KV to 100 KV -- will be fed through 25 KV hook operated disconnects from the bus. This transformer will have four 2-1/2 percent taps so that it can be fed at 22.5, 23.1, 23.8, 24.4 or 25 KV. This transformer output at 100 KV will use size 636 MCM ACSR leads to rise to a 115 KV air break switch at the top of a standard steel transmission line tower adjacent to the substation.

An auxiliary transformer rated 25/33/42 MVA-OA-FA/FA -- 25 KV to 13.8 KV -- with taps similar to those in the main transformer will be installed with suitable hook operated disconnects on both the 25 KV and the 13.8 KV side. The principal motor loads to be supplied from the 13.8 KV bus are the air separation unit and the oxidizer unit totaling just under 25,000 H.P. The other motor loads are to be determined and will probably all be supplied by 480 volt three phase service which will require a transformer from 13,800 to 480 volts.

As indicated on the one-line diagram, the transmission line using size 636 MCM ACSR conductor may require two steel towers and will be approximately 600 ft in length to reach the northwest corner of the 100 KV ring bus at the Billings Steam Plant Substation. Care should be exercised to assure that proper clearance from all structures, ground, rails, and other conductors is

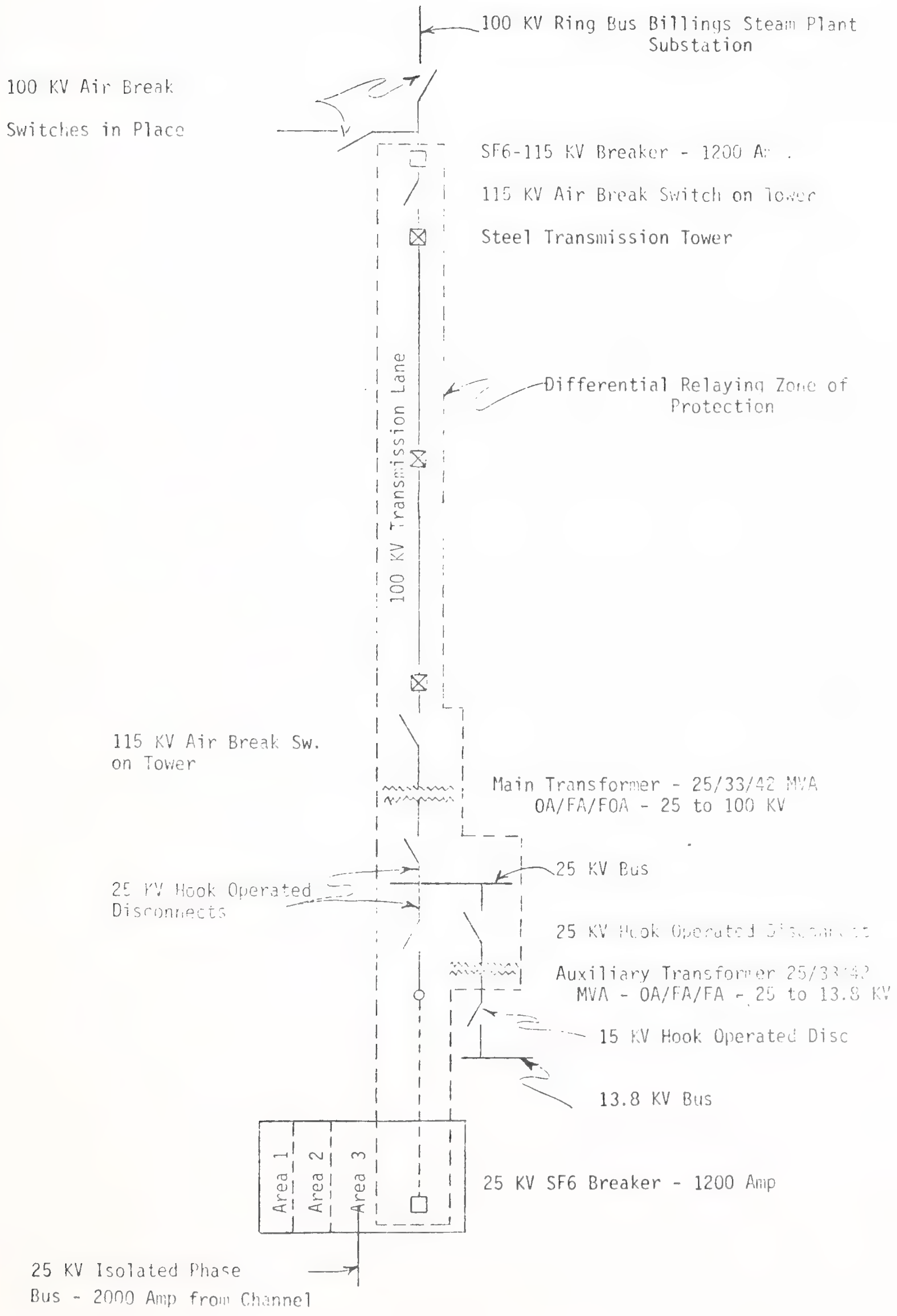

100 KV Ring Bus Billings Steam Plant Substation
100 KV Air Break Switches in Place
SF6-115 KV Breaker - 1200 Amp
115 KV Air Break Switch on Tower
Steel Transmission Tower
100 KV Transmission Lane
Differential Relaying Zone of Protection
115 KV Air Break Sw. on Tower
Main Transformer - 25/33/42 MVA OA/FA/FOA - 25 to 100 KV
25 KV Bus
25 KV Hook Operated Disconnects
25 KV Hook Operated Disconnect
Auxiliary Transformer 25/33/42 MVA - OA/FA/FA - 25 to 13.8 KV
15 KV Hook Operated Disc
13.8 KV Bus
Area 1
Area 2
Area 3
25 KV SF6 Breaker - 1200 Amp
25 KV Isolated Phase Bus - 2000 Amp from Channel

Figure 2-21 -- Substation and Transmission

adequate. The tower adjacent to the 100 KV ring bus will support a 115 KV air break switch and this will feed a type SF6 115KV circuit breaker to be connected to the 100 KV ring bus. This SF6 circuit breaker will be equipped with proper bushing-type current transformers for differential relaying. There will be corresponding current transformers in the 25 KV SF6 breaker in the inverter building and on the 13.8 KV side of the auxiliary transformer. The secondary leads from these three locations will be arranged for differential relaying to open the 25 KV-SF6 breaker in the inverter building and the 115 KV-SF6 breaker near the ring bus. Any fault in the underground cable system, the 25 KV bus, the main transformer, the auxiliary transformer or the transmission system will cause these two breakers to open at high speed, giving adequate protection to the total system.

With the air breaks in the 100 KV ring bus and with the disconnect equipment planned, each piece of equipment and the transmission system can be individually isolated for any required maintenance work or inspection.

2.3 Utility Interfaces

The interfaces with the Corette plant are primarily in the steam, feedwater, water systems, coal, and control areas. Additional interfaces that involve the Bird plant as well as the Corette are the natural gas, fire protection, and the central control room. The major electrical interface is in the Billings Steam Plant Substation.

2.3.1 Steam

The design requirements for the steam interface between the ATS and the Corette plant should ensure that operational and functional impacts will be minimized. The high pressure systems should integrate readily with the existing systems and be easily controllable to respond to operational requirements. The Corette boilers minimal operational level should remain at an efficient and responsive level while allowing the steam electric turbine generator to operate at its nominal 163 MW_e level. Steam pipelines should be as short as practical to minimize heat and pressure losses and continue to allow adequate short time control responses.

Some lower pressure steam requirements, if available from the existing system, will be necessary to provide a heat source for ATS building heating loads in the heating/ventilating units. All of the new steam systems will require a method to capture condensate and return it to the Corette condensate system.

There will be three interface connections to the High Pressure Superheat Steam and Reheat Steam Systems to accommodate the additional steam as supplied from the HRSR boiler. The superheat steam flow will be controlled by the feedwater flow control valves, as shown on schematic Figure 1-1. The Corette boiler will be operated at approximately 67% of firing rate and the HRSR would then supply the additional 33% of steam flow to operate the turbine-generator at its nominal rating of 163 MW_e. The boiler recovery factor and efficiency curves of the Corette unit indicate that it be operated in the 60 to 70% range to minimize operational problems and still retain cost effective power generation. MPC may, at their discretion, operate at a turbine-generator output higher than the nominal 163 MW_e. An internal design evaluation of required steam flow, turbine stresses and other plant operating and capacity requirements would have to be made to ensure that the turbine generator is capable of the higher output. The Corette boiler would be capable of providing the additional steam requirements under those operating conditions and the turbine-generator could potentially reach an output of 182.4 MW_e.

The interface connection on the high pressure superheated steam will be into the existing 14 in. diameter steam line as it is routed to the turbine. The connection will be in the main ground floor pipe alley at an elevation of approximately 15 1/2 ft above ground floor.

The cold reheat steam interface will be at a similar location approximately 12 ft above ground level along the main ground floor pipe alley. That connection into the 24 in. diameter cold reheat steam line will be as close as possible to the turbine to provide adequate control sequencing and response time in the system.

The hot reheat steam interface will also be in the main ground floor pipe alley approximately 12 ft above the floor. This connection will be into the existing 22 in. diameter hot reheat steam line.

To provide heating in the new facility the existing 175 psig steam system will be interfaced and extended to the heating/ventilating units in the areas requiring heat, if design calculations confirm steam availability. This expansion of an existing system ensures adequate freeze protection of the new buildings during periods of non-MHD operation.

Figure 2-22 outlines the major steam interfaces and Table 2-9 summarizes the steam and feedwater flows at boiler stop valves.

Additional interfaces will be required to adequately collect any low pressure or high pressure condensate drains. Those drains will be connected to the appropriate condensate system now in use at the Corette plant which returns to the turbine condenser.

2.3.2 Feedwater

The feedwater requirement for the HRSR should be of similar quality as is presently fed to the Corette boiler. To overcome additional frictional losses in the piping system, provision should be made to increase the pressure of that feedwater. The interface should ensure that operational and functional impacts are minimized and that ease of operation with adequate responsiveness remains.

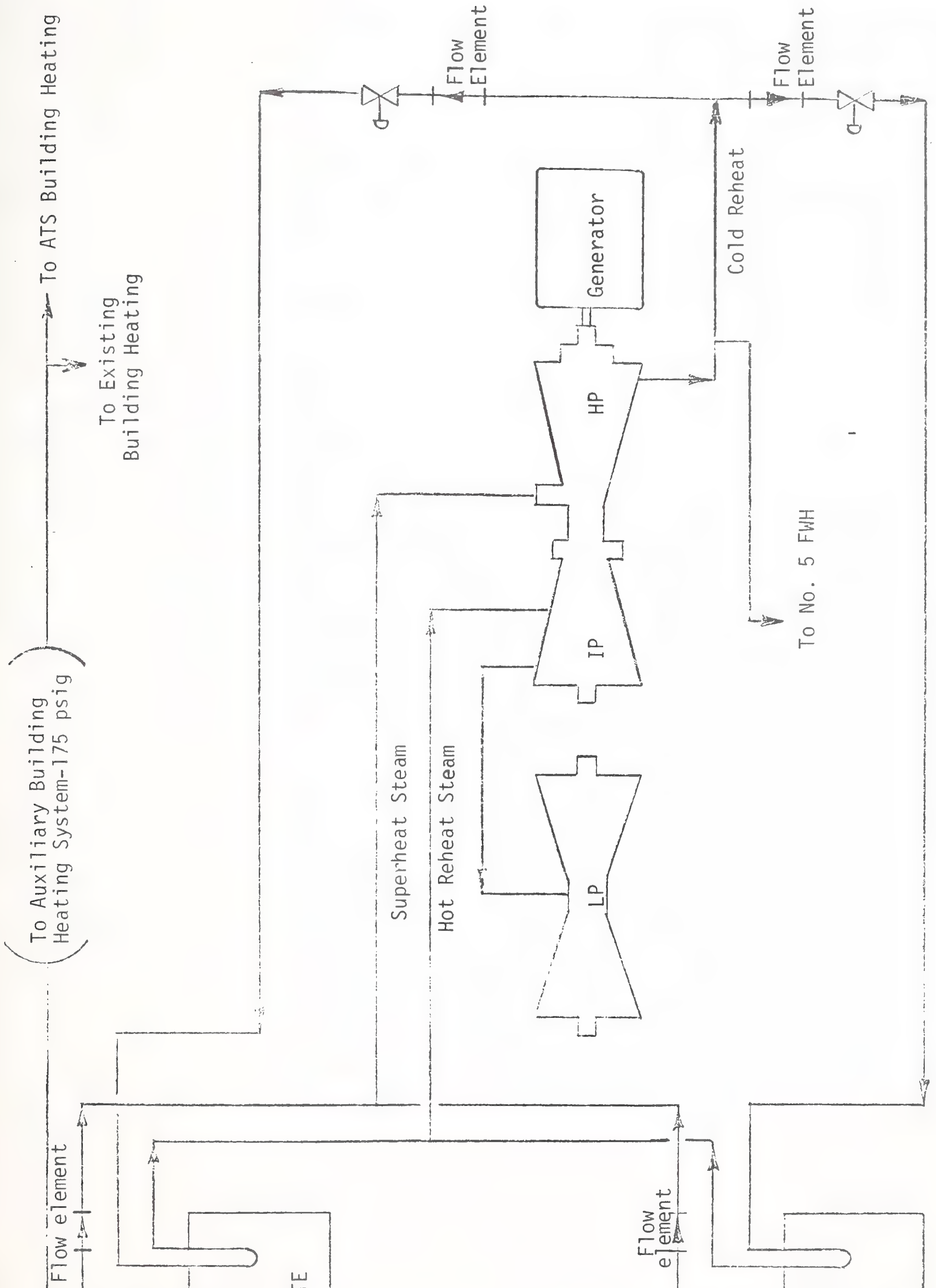


Figure 2-22 -- Steam

TABLE 2-9

BOILER STOP VALVE

STEAM AND FEEDWATER CONDITIONS

Item	Source	To	Lbm/Hr
Superheat Steam	Corette	Turbine	7.462×10^5
Superheat Steam	HRSR	Turbine	3.675×10^5
Total Superheat System		Turbine	1.1137×10^6
Cold/Hot Reheat Steam	Turbine	Corette	6.363×10^5
Cold/Hot Reheat Steam	Turbine	HRSR	3.134×10^5
Total Cold/Hot Reheat System		Corette/HRSR	9.497×10^5
Feedwater	FW Heater	Corette	7.500×10^5
Feedwater	FW Heater	HRSR	3.692×10^5
Total Feedwater		Corette/HRSR	1.1192×10^6
Blowdown	Corette/HRSR		0.055×10^5

The HRSR boiler feedwater requirement will be supplied by the existing Corette feedwater system, as shown in Figure 2-23. The assumption is made that at the reduced rate of firing in the Corette boiler, adequate feedwater is available to both boilers as the combined steam flow to the turbine-generator remains at its nominal operating level of 163 MW_e. The existing evaporative makeup system will be assessed for adequacy to provide adequate makeup water supplies to offset boiler blowdown, sampling, or other losses. If MPC elects to operate the turbine-generator at an output greater than 163 MW_e they would conduct an internal design evaluation of the required feedwater and condensate flows.

An electrically driven booster feedwater pump in the feedwater line to the HRSR will be required to overcome additional pipeline frictional resistance. That resistance is due to increased length of pipe runs to the HRSR and the cooling loops through the combustor and diffuser. Initial filling of the HRSR will require plant coordination during periods of normal Corette boiler operation.

The feedwater interface connection will after the No. 5 feedwater heater. The location of the connection will be in the main ground floor pipe alley in the vicinity of the existing feedwater pumps and approximately 12 ft above ground level. Figure 2-23 shows the major feedwater flows for the Corette ATS plant.

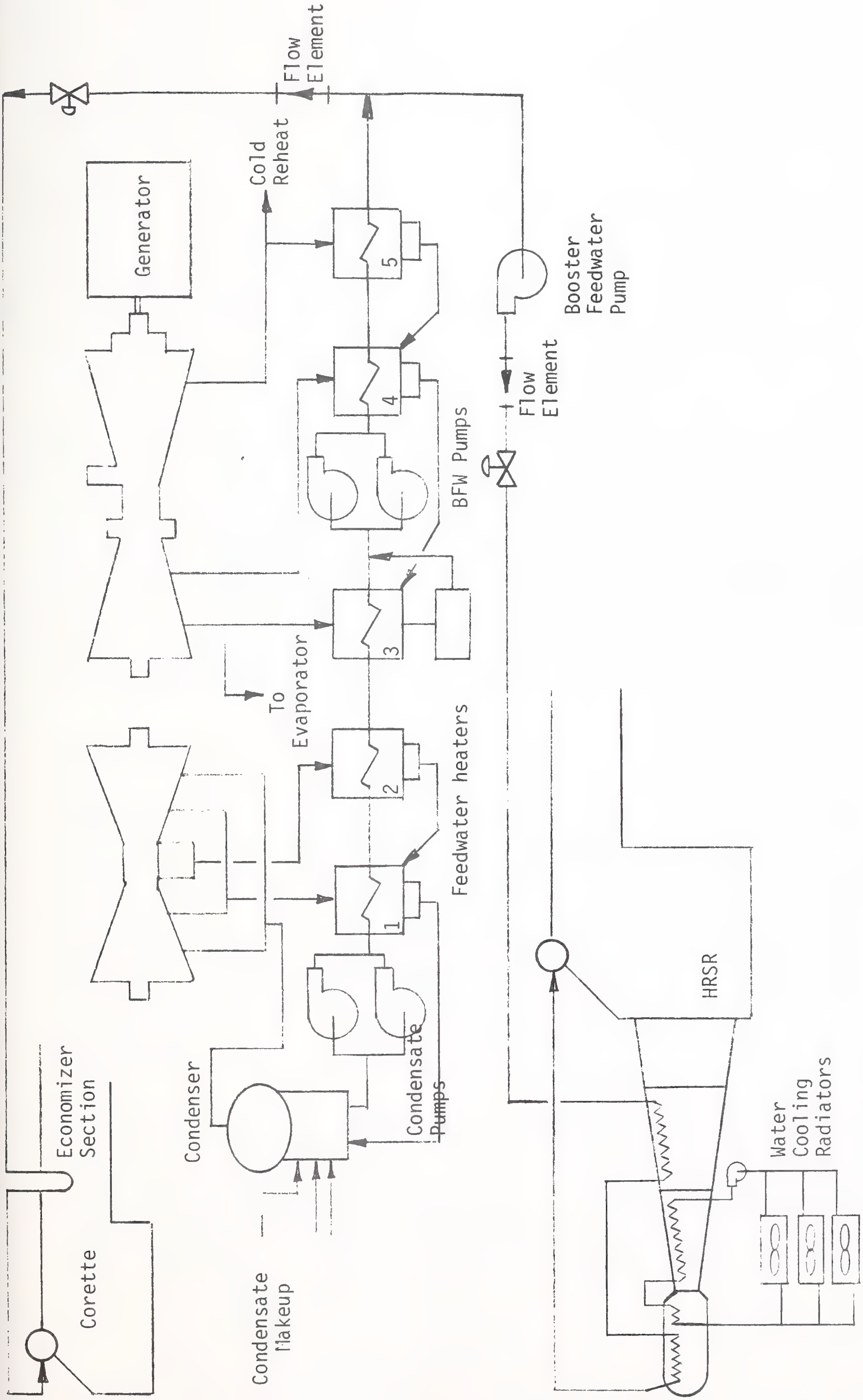


Figure 2-23 -- Feedwater

2.3.3 Water Systems

Interface design requirements for the closed-loop cooling water systems will require initial filling and makeup of high quality water to minimize corrosion, scaling, and makeup requirements in the various sytems. A source of cooling water from the Yellowstone River is required to dissipate low-grade heat from mechanical equipment as well as provide minimum usable requirements in the ATS. Consumable water usage and clean filtered water requirements should be supplied from the city water supply. Additional fire protection requirements should be satisfied from the existing plant-wide fire protection system. Sketches provided in previous sections have indicated interface requirements on these systems. A separate table showing total water requirements is included in this section.

The MHD channel cooling water system, inverter cooling water system, and the bearing cooling water system will have an interface with the Corette condensate system. Initial filling of the system will be with that high quality water. During normal ATS facility operation the water makeup will be minimal and should be satisfied from the Corette system. Coordination between the two plants will be necessary during the initial filling to minimize any impacts with the Corette boiler operation.

A separate service water pump will be installed to provide primary cooling water requirements to the lube oil coolers and makeup water requirements to the CFC slag handling system, HRSR bottom ash system, blow-off quench tank, and washdown hoses. The pump will use an existing intake structure located

on the Yellowstone River. Heat load requirements will have to be balanced between the ATS and Corette plants when both are operating and providing steam to the turbine-generator at the nominal 163 MW_e level. An internal design evaluation of cooling water requirements would be made if turbine-generator output beyond 163 MW_e was desired.

A potable water break tank similar to the existing one would be installed to provide a constant head for pump gland seal water and consumable potable water usage. The interface and supply will be from the existing plant city water system.

The existing fire system will be interfaced with and be extended around the new building perimeter if design calculations determine the adequacy of the present systems. Wet risers for the ATS will then be supplied from the perimeter fire main system.

Table 2-10 summarizes the water usage requirements for the ATS.

2.3.4 Fuels

Two fuel interfaces are required with the existing Corette and Bird plants, the major one being the primary fuel, coal. The second requirement will be for a natural gas supply from the present system connected to both the Corette and Bird plants.

TABLE 2-10

WATER USAGE

	GPM	T°F	Blowdown	Makeup
Feedwater	905	--	18	18
MHD Channel Cooling	3700	20°	--	15
Inverter Cooling	200	20°	--	5
Bearing Cooling	2100	73°	--	25
Service Water	3000	51°	--	--
Potable Water	40	--	--	40
Fire Protection	As Required			

2.3.4.1 Coal

The interface design requirement for coal, the major firing fuel, is to provide an adequate supply of coal to the ATS while not interrupting the present supply of coal to the Corette plant. Interfacing with the existing coal supply system would simplify the coal system design and would greatly reduce the construction costs of that system.

The interface would be at the existing coal reclaim tunnel or optionally along the existing No. 5 coal conveyor. A new conveyor will then transfer a side stream of coal to the ATS coal bunkers for further processing in the coal preparation system. The existing reclaim system was designed to handle 200 tons per hour, a sufficient flow for two units the size of Corette. As the Corette's maximum operating design is 100 tons per hour the requirement for an additional 50.7 tons per hour of coal to the ATS can be met. Refer to the sketches and tables in the previous sections for details of the coal preparation system.

2.3.4.2 Natural Gas

There is a requirement for a pilot fuel in the coal fired coal predryer, pulverizer air heater, and the MHD coal-fired combustor (CFC) for startup and stabilization during firing. In addition, startup, off-load, and abnormal operation of the ATS will require an alternate fuel to stabilize the HRSR operation and provide a more compatible steam interface with the Corette plant.

An interface with the existing Heart Mountain natural gas regulating station will supply fuel to the pilot ignitors on the coal predryer, pulverizer air heater, and the CFC. The natural gas supply will be adequately sized to provide the potential firing of the HRSR boiler during periods of non-MHD operations. This is not a continuous operating mode but would allow the combined plant an opportunity to compensate for off-load or abnormal operating conditions.

The existing regulated natural gas system has an approximate capacity of 900 MCFH for the Corette unit warm up guns and rated firing of the Bird unit. The sketches in previous sections detail the gas system. The use of pilot ignitor gas would only be during initial firing of the coal predryer, pulverizer air heater, or CFC. Approximately 200 MCFH of gas would be used during alternate firing of the HRSR with 30% rated warm up guns. The total available supply of gas would probably eliminate the HRSR firing when the Bird unit was needed on line.

2.3.5 Instrumentation and Control

It is planned that the existing utility plant will be treated as a local system and be controlled by the supervisory computer control system through commands to the existing control system. Operating points, such as modes (boiler following, turbine following) and operating power levels will be set by the supervisory computer. Steam system operating parameters and alarm levels will be returned to the supervisory computer for status monitoring and for integrated plant control in the event of an emergency. There will be only a few high bandwidth interconnections that will be routed from the existing Corette control room to the individual ATS subsystem control microcomputers.

The utility, in this case Montana Power Company, will have operational control of the supervisory computer.

2.3.6 Electrical

The plan is to locate the steel substation so that the transmission tower nearest the substation will clear the coal conveyor. There is some cable power wiring and a telephone cable on the No. 5 coal conveyor steel support towers. These cables can all be raised or re-routed on the support towers to remain in the clear of the proposed substation.

The 100 KV transmission line will be about 600 ft long and will extend to a vertical corner pole directly west of the construction warehouse, with an overload guying arrangement over the railroad tracks and toward the day fuel oil tank. From the vertical corner pole, the line will run in a direct line to dead-end on the existing steel tower at the northwest corner of the 100 KV ring bus. A layout is shown on the Billings steam plant site plan.

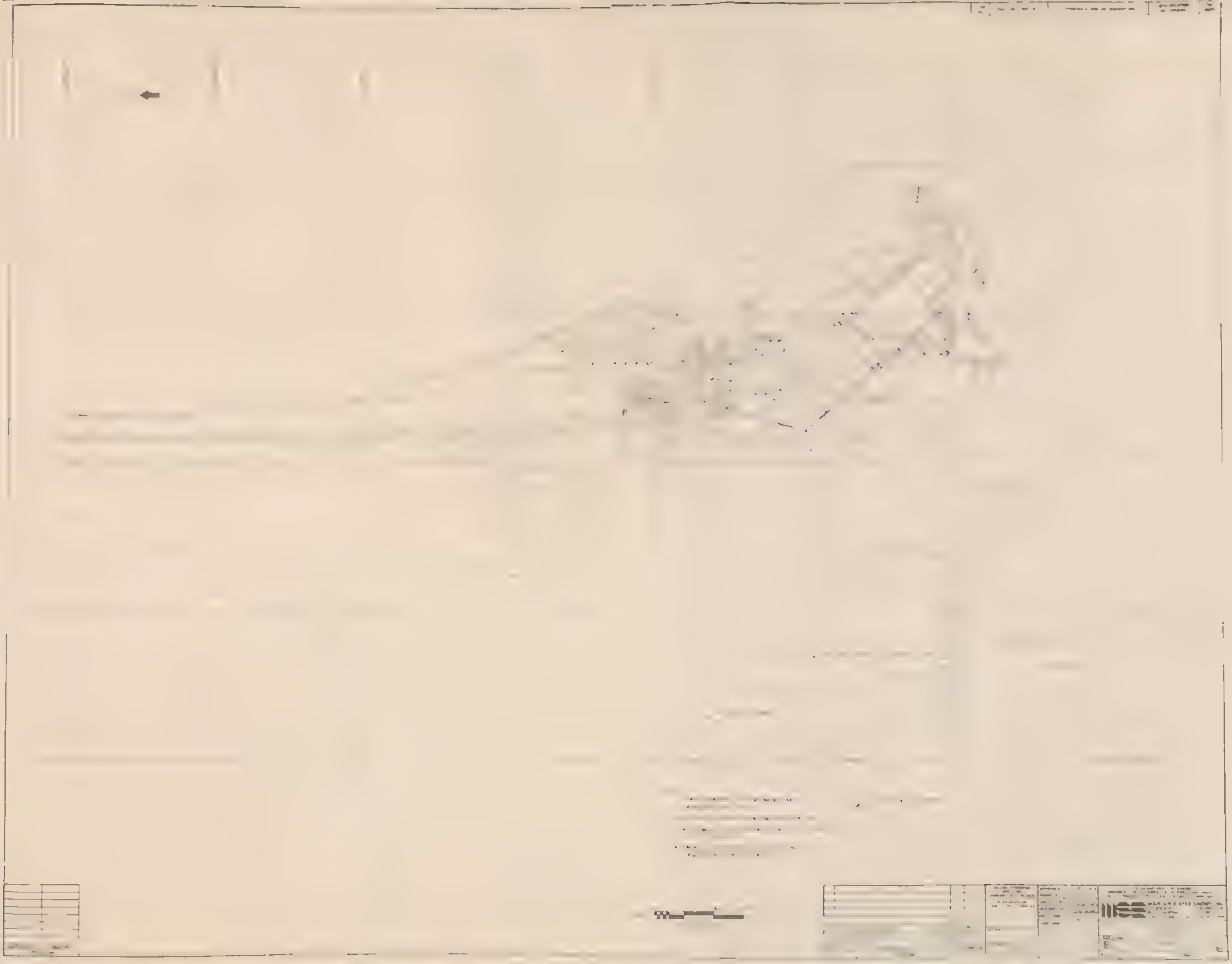
The differential relay arrangement will protect the Montana Power Company 100 KV ring bus from any faults between the inverter and the bus with high speed switching of the SF6 breakers.

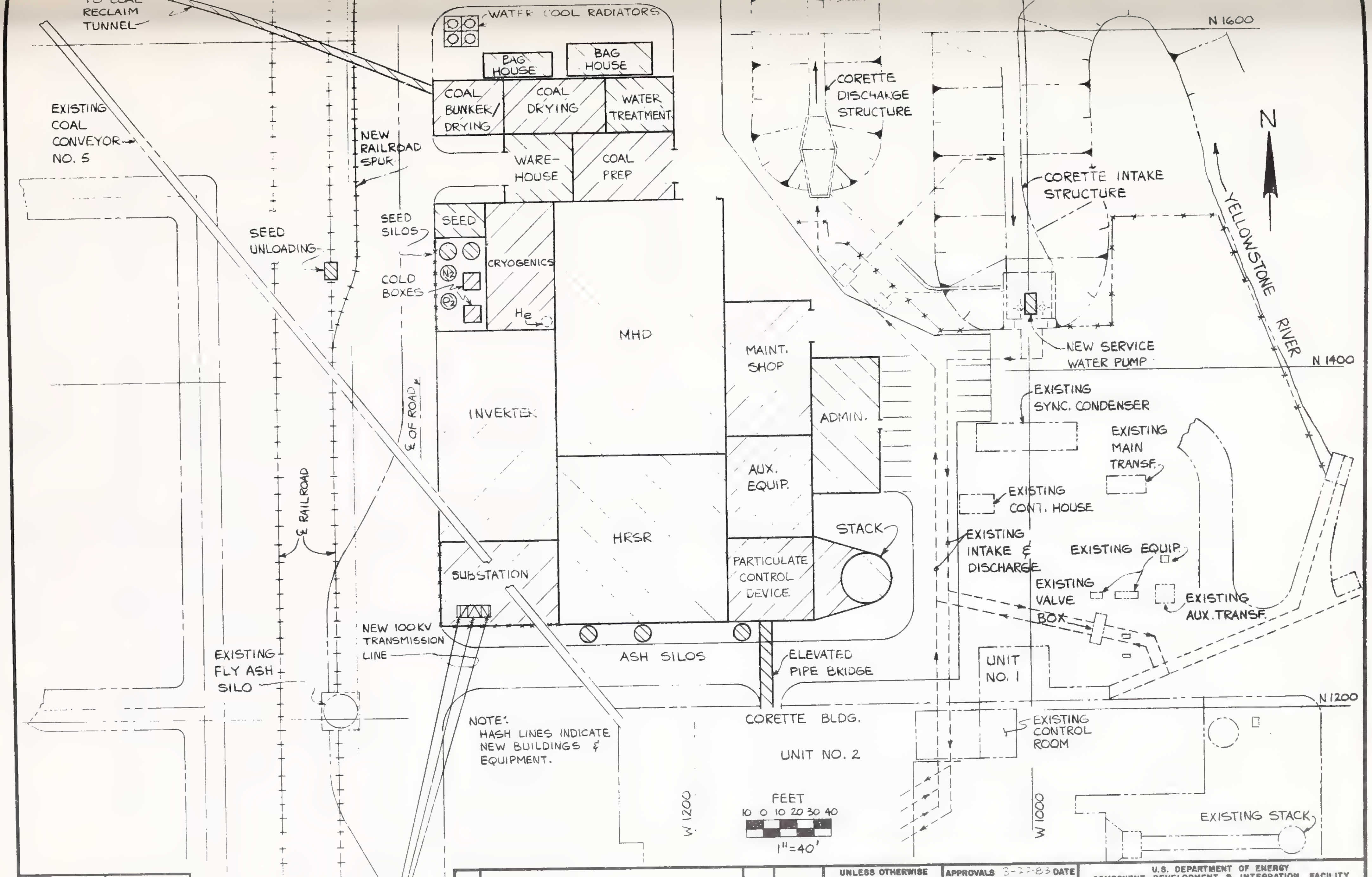
2.3.7 Buildings and Structures

One of the previously stated design requirements was for close proximity of the HRSR to the existing Corette turbine-generator to reduce steam and

feedwater pipeline lengths. This necessitates that the ATS should be located adjacent to the Corette plant taking into consideration existing road and access requirements for the Corette. This close location would also reduce the lengths of interface connections required for the closed cooling water loops, service water intake structure, potable water, fire protection system, and primary fuel. The existing coal reclaim system should be used to reduce duplication of systems. Utilizing the available land and area as well as providing access to the Corette unit and the existing operating offices is a requirement for the design. The ATS should be located to effectively use the existing rail and road facilities for access during construction, startup, and operational phases of the project. Any rail or road movement must be coordinated with the Corette plant to not interrupt coal unloading operations. Control of the Corette must be closely coordinated with any operational requirements of the ATS, therefore, making the physical proximity of the controls for both plants a necessity. The minimization of costs by locating buildings and structures in a fairly unrestricted area adjacent to the existing plant and interfacing with existing operational equipment is a primary design requirement objective.

The ATS building, structural, and area layout is shown on Figures 2-24 and 2-25. This layout shows an integrated island within the available area adjacent to the Corette plant. Locations of specific interfaces, such as the service water pump, control room, pipe bridge, seed railcar unloading and coal conveyor takeoff, are determined by existing plant and equipment configurations.





LTR.	DESCRIPTION	DATE	APPROVED
B	REV-DRK 2875	4/11/83	RDM
A	DRR 2843	3/3/83	3Kn
+	DRR 2698	4/5/83	—

REVISIONS

NEXT ASSY. | USED ON
APPLICATION

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES
TOLERANCES ON FRAC. DEC. ANGLES
MATERIAL:
SURFACE FINISH AS NOTED

APPROVALS 3-22-83 DATE
DRAWN BY: Jean Farah
CHECKED BY: R J Bushman
DESIGNED BY: R.J Bushman
PROJ. ENGR.
ENGR. MGR.

U.S. DEPARTMENT OF ENERGY
COMPONENT DEVELOPMENT & INTEGRATION FACILITY
BUTTE PROJECT OFFICE MHD/ID BUTTE, MONTANA

MOUNTAIN STATES ENERGY INC.
P.O. BOX 3767
BUTTE, MONTANA
(406) 494-7100
FTS 587-7100
DOE CONTRACT AC07-78-ID-01948

TITLE: CORETTE PLANT MHD PLAN VIEW
SIZE C
DWG. NO. C02-DNRC-004
REV. B
SCALE: 1"=40'
SHEET 1 OF 1

FIG. 2-25

2.4 Site

This section will address the land and area requirements of the MHD power train and the support systems of the ATS. The location available at the MPC thermal plant facility at Billings, Montana is limited in area and in configuration. The site available is bordered on the west by the main access road, railroad service, fuel oil storage tank, and coal storage; on the south by the Corette and Bird thermal power plants; and on the east by the Bird plant main transformer, and the intake and discharge canals for the Corette plant. The Yellowstone River also confines the eastern as well as the northern boundary of the available area for the ATS. Preliminary sizing was done in preceding sections and those building descriptions were used in developing the general plot arrangement as shown on Figures 2-24 and 2-25.

2.4.1 MHD Systems

The basic MHD layout lies immediately north of the Corette plant and was arranged to minimize the lengths of the superheat, cold reheat, and hot reheat steam lines to the turbine-generator. Access to the main service doorway on the north side of the Corette was also required as well as access to the operational offices of the present facility. The cryogenic building was located as close as possible to the SCM to eliminate lengthy liquid helium lines. The inverter building was also located close to the MHD channel to reduce the length of the DC power transmission lines. The coal bunkers and coal preparation facility were located to provide ready access to the existing coal reclaim system and to isolate any potential fire and explosive hazard from the existing Corette plant. A direct route

for the main 100 KV transmission line was also considered in the layout of the buildings and structures. Some interference with the existing No. 5 coal conveyor was a concern and layouts were made to avoid that problem. The remainder of the facility was arranged to provide access for equipment maintenance, ease of bulk consummable commodity delivery, and convenience for removal of bulk waste material within the physical confines of the area.

Initial construction, startup, and operational phases will require considerable interface with contractors, suppliers, manufacturers, and technical personnel. Separate construction management offices, construction personnel parking, and construction staging areas will have to be coordinated during the various project phases. The administration building was sized to accomodate nominal staffing requirements for those phases of the project and also provide the future capability to convert those offices and facilities to operational offices. As such the administration building required adequate roadways and parking areas in close proximity.

2.4.2 Interface Systems

The interface system discussed in this section will be those areas of direct interface with the existing Corette plant that impact siting considerations.

2.4.2.1 Steam and Feedwater

Superheated steam, cold and hot reheat steam, and feedwater will be the primary interface between the ATS and the Corette Plant. Those interface connections will be in the main ground floor pipe alley of the existing plant

and a main pipe bridge between the two facilities. Other interfaces, such as 175 psig steam, evaporator water and potable water, will be routed over this pipe bridge. A pipe alley will be incorporated within the new building structures and will include other piping runs as required. Due to the closeness of the two facilities the interconnecting pipe bridge will not require extensive additional area.

2.4.2.2 Water Systems

Any site considerations for the various water systems is determined by the system itself and its interface with the existing plant. The service water system will utilize an existing intake structure with the pump mounted on the concrete pad. The pipeline will be buried deep enough to avoid freezing, although it will traverse the existing underground pipelines from the Corette intake and discharge structures.

The water cooling radiators for the channel inverter cooling water system will be located to take advantage of prevailing winds and not interfere with nearby structures. The supply and return pipelines will be located within the confines of the ATS and should not interfere with any of the existing plant related equipment.

The existing underground perimeter fire protection system on the north side of the Corette Plant will lie underneath the ATS buildings. That fireline would be relocated to provide perimeter protection to the new buildings as well as continuing the fire protection for the existing plant.

2.4.2.3 Fuels

The interface for the natural gas will be at the existing regulating station located south of the Corette main transformer. Routing of that underground pipeline will parallel the existing six-inch pipeline to the Corette boiler which runs outside of the building along its south and west side. The new gas line will continue to points of use in the ATS with no further interface anticipated.

The interface with No. 5 coal conveyor will be at the coal reclaim system inside the coal reclaim tunnel or optionally could be located along the length of No. 5 coal conveyor. This decision will be made during the design phase of the project when further analysis of costs, operational requirements, accessibility, interferences, and additional interfaces can be made. The new coal conveyor will be routed overhead above the railroad and main access road to alleviate clearance and interference problems. It will discharge on top of the new coal bunkers for distribution to those two bunkers.

2.4.2.4 Electrical

The inverter will have a major interface connection to the existing switchyard with the appropriate towers and 100 KV power lines. The location of the main transformer and tower support is critical to miss any overhead interference with No. 5 coal conveyor and to establish a direct routing to the 100 KV bus in the switchyard.

2.4.2.5 Bottom Ash

The existing 10 in. cast bottom ash pipeline discharge from the Corette boiler runs in a northerly direction above ground to the bottom ash disposal pond. That pipeline will have to be relocated to skirt around the new building structures of the ATS.

The existing 36 in. yard drainage pipeline with the various catch basins and the oil separation discharage pipeline will have to be relocated to miss the new building foundations.

2.4.3 Liquid Waste Storage and Disposal

Waste water from the ATS will consist of water from the CFC slag handling system, bottom ash sluicing system, blow-off quench tank, demineralizer regeneration, and floor drains. All of these flows will be directed to the water treatment plant where they will be processed for recycling or eventual discharge to the Yellowstone River via the existing bottom ash ponds. The bottom ash ponds should be evaluated for loading consideration and environmental consequences during the conceptual design. Due to the intermittent nature of the discharges there will be surge capacity storage at the water treatment plant to stabilize water treatment processing flows and provide for unusual operating conditions of the ATS. All floor drains will be routed through an oil separator before surge tank storage. The routing of the discharge pipeline to the Yellowstone River will traverse an open area and should pose no siting problems. Figure 2-26 identifies the major sources of liquid waste and water treatment process.

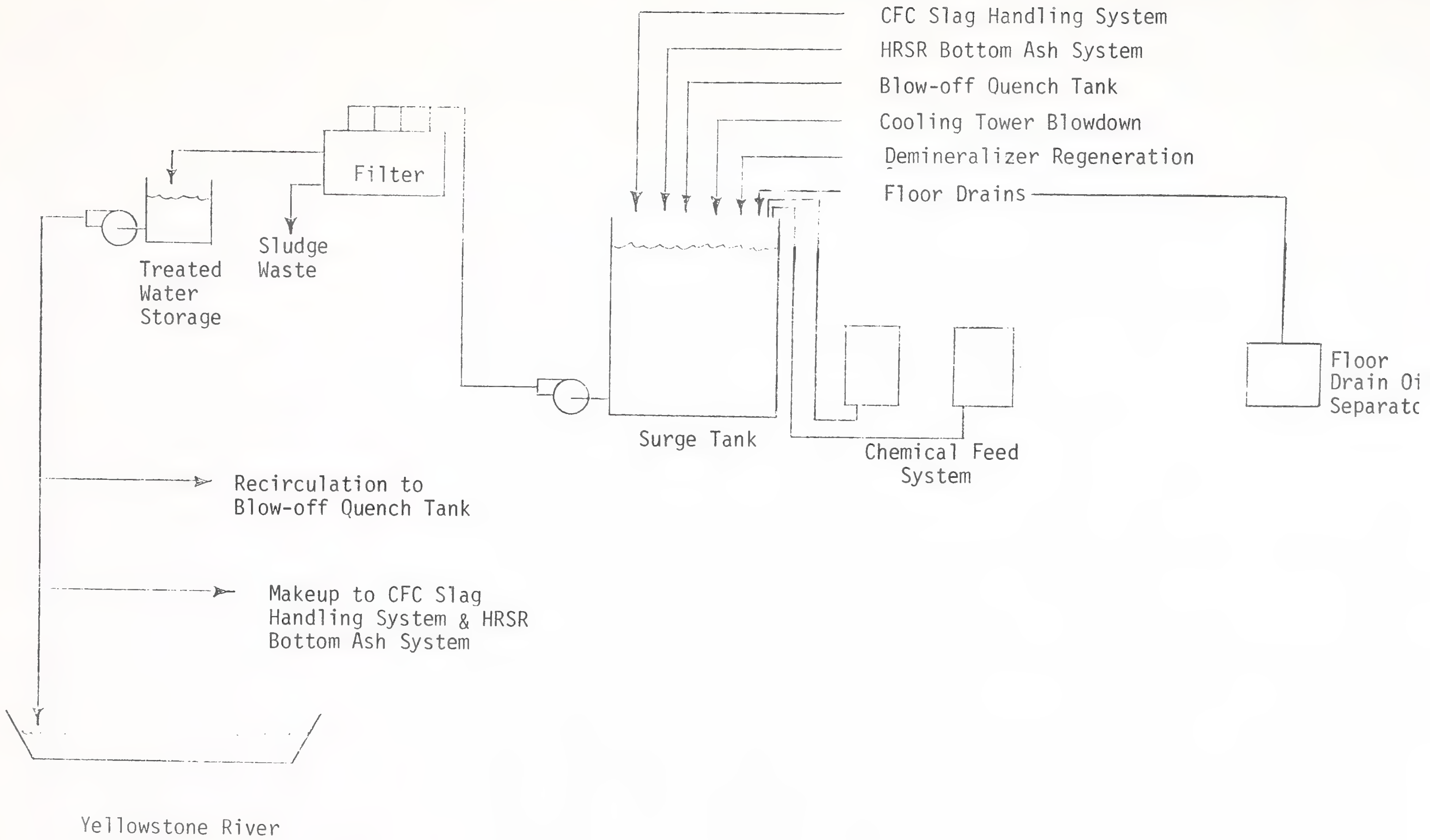


Figure 2-26 -- Liquid Waste

2.4.4 Solid Waste Storage and Disposal

The dewatered slag from the CFC slag handling system will constitute the largest volume of solid waste material requiring disposal. This material will be transferred from the dewatering bins to intermediate storage where it can then be sold for asphaltic material or optionally loaded onto trucks for off-site disposal at a land-fill area. Some filter sludge will be generated by the filtration process in the water treatment plant and will have to be disposed off-site. The bottom ash sluicing system will also use dewatering bins with an intermediate storage for disposal of the dewatered bottom ash.

Each fly ash silo will have material with varying percentages of potassium related compounds and fly ash. The silos and intermediate bottom ash storage will have provisions for truck loading and the material with high potassium content will be transported off-site to a permanent storage facility for future processing. The remainder of the material will be disposed at a land-fill area or sold as a cement filler. Figure 2-27 identifies the source and disposal of the ATS solid wastes.

2.4.5 Transportation

The site currently has rail transportation service from Burlington Northern Railroad and has adequate trackage and spurs for the ATS and the present plant requirements. The location of the main trackage is parallel to the ATS and will enable the construction of a short spur to accomodate off-loading major ATS construction components close to the new installation. Railcar delivery of consumable material would be advantageous and readily designed

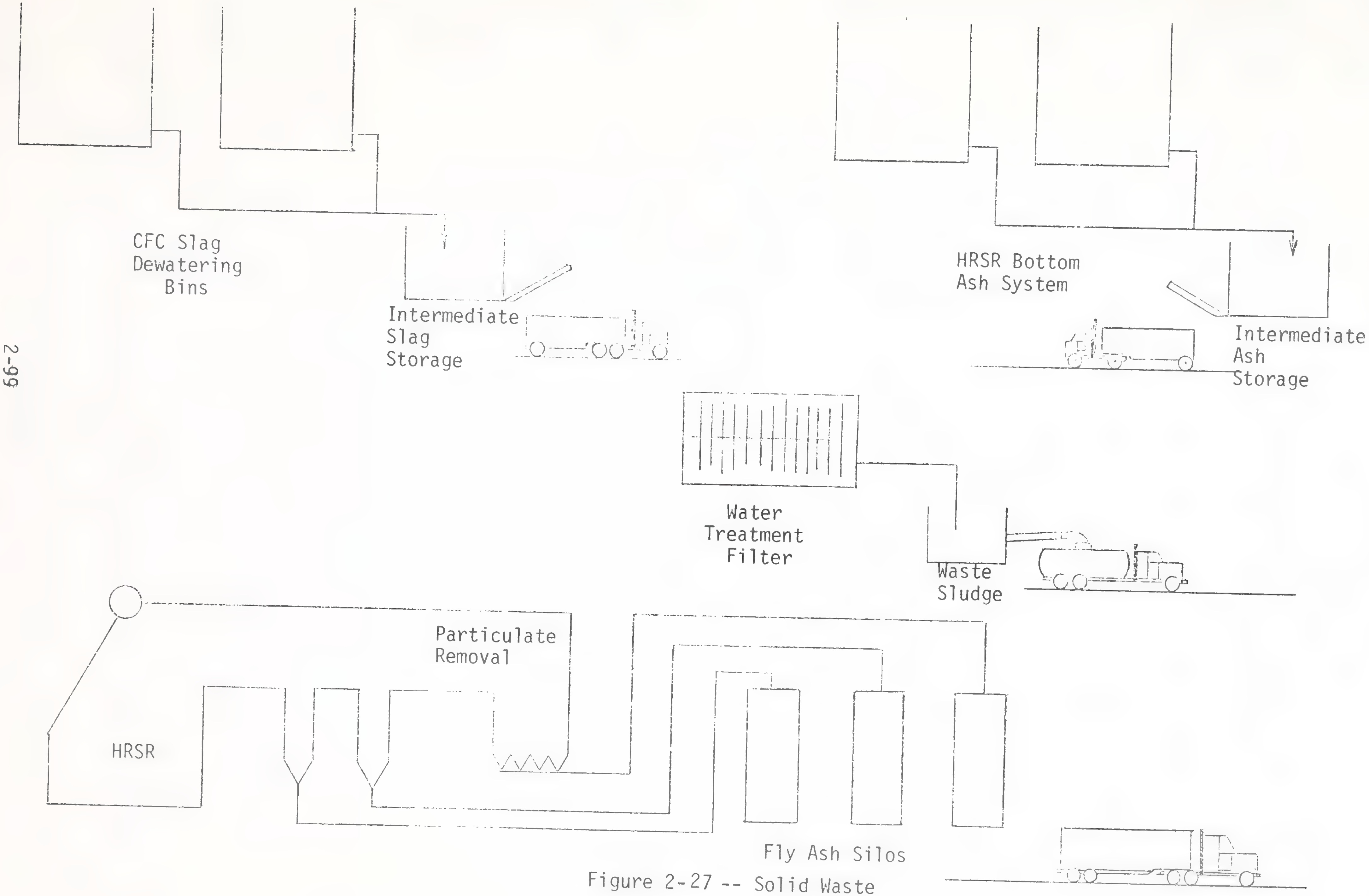


Figure 2-27 -- Solid Waste

into the facility. The primary material delivered by rail would be seed and should not interfer with coal delivery. Consumption is minimal with deliveries anticipated every seven to ten days during continuous operation.

The City of Billings is on the national interstate highway system and the MPC site is adjacent to Interstate 90 with access within one-half mile from the plant site. The site roads are adequate for delivery of material and equipment of the sizes anticipated for construction and operation of the ATS. Provision for road access to the north side of the Corette plant will be required to allow continuation of the existing operational and maintenance activities.

2.4.6 Land, Building, Structures, and Area Requirements

The layout of the buildings and structures on the available land, as shown on Figures 2-24 and 2-25, was predicated in regard to the following: 1) maintaining close proximity to the turbine-generator; 2) utilizing existing main roadways and railroad trackage; 3) adjacent to coal transfer points; 4) closeness of existing plant services; and 5) minimization of the cost of construction and plant modifications.

In general, all buildings will be of steel frame construction with insulated metal siding and built-up roofing. Buildings adjacent to each other will share common wall construction. Mandoors, large access doors, and stairwells will be integrated within the entire complex as well as a centrally located elevator for personnel and maintenance access. Heating/ventilating and air conditioning systems will be integrally designed as a part of the structures

paying particular attention to comfort zoning and fire protection requirements.

2.4.6.1 MHD

The MHD building will be located at the center of the MHD complex with access to roadways for ease of entrance or egress. It will house the coal-fired combustor (CFC), MHD channel, diffuser, superconducting magnet (SCM), channel and magnet control instrumentation, slag quench tank, slag dewatering bins, and the magnet D.C. power supply. The walls adjacent to the operating field of the SCM will be shielded to prevent magnetic fields from affecting equipment or personnel. Shielded internal walls in the building will be required to take advantage of the entire area for auxiliary equipment and allow for operating or maintenance access. The 100 ft by 150 ft building will be 80 ft high. A 150 ton bridge crane will span the 100 ft width of the building and be used to facilitate the initial erection of the equipment and for continuing maintenance operations. The magnet is mounted on a foundation and the MHD channel is inserted and withdrawn from the large exit end of the SCM for maintenance. To facilitate slag rejection from the CFC and to eliminate construction, maintenance, and housekeeping problems a ground level handling system, including slag dewatering bins, is recommended.

2.4.6.2 Control Room

The central supervisory control for the ATS operation will be located in the existing Corette control rooms. The data acquisition system (DAS) will be included in this area as an integrated part of the control functions.

2.4.6.3 Heat Recovery/Seed Recovery

The HRSR will be housed in a 100 ft by 100 ft building envelope with a height of 80 ft. The radiant and the convective portions of the HRSR as well as the economizers and air heaters will be housed in this building. The lower floor levels will include such major equipment as the circulating boiler pump, booster feedwater pump, bottom ash sluicing system, seed and ash collection systems, and various air blowers. The ash sluicing system will use dewatering bins that can be located inside the HRSR building. The recovered seed and ash material will be transported to outside storage silos where it will be removed for off-site storage or disposal.

2.4.6.4 Inverter

The inverter building will house the thyristors, inverter, switch gear, and instrument and control functions. The 125 ft by 70 ft structure will be 24 ft in height. The building will be located as close to the MHD building as possible to keep interconnecting power transmission line losses to a minimum. The main transformer, auxiliary transformer, and necessary towers will be located in a a substation area of 70 ft by 50 ft that would be close to the building with clear access toward the existing switchyard. The water cooling radiator for the thyristor heat load will be located at the edge of the complex to take advantage of a more open area.

2.4.6.5 Coal Preparation

The coal preparation area will include two coal bunkers (33 ft x 21 ft each) at the north side of the ATS facility. A new take-off point at the coal reclaim tunnel or along No. 5 coal conveyor will provide coal feed to these bunkers. The bunkers will discharge to the coal crusher and predryer which will be located immediately below the bunkers in an open steel frame coal drying building with dimensions of 33 ft by 100 ft. The upper height of the coal bunkers will be 80 ft and the portion of the coal drying building not underneath the bunkers will have a roof elevation of 24 ft. The bag house for the coal predrying will be located north of and adjacent to the building. The 30 ft high bag house will cover a 40 ft x 15 ft area.

The adjacent coal preparation building will house the remaining components such as coal pulverizers, storage vessels, injection vessels, and conveyors. The 40 ft by 60 ft structure will be 80 ft in height. This building will have blowout panels due to the combustible nature of the finely pulverized and dried coal. The cyclone will be located on the roof of this building and the bag house (for the coal preparation system) will be to the north of the ATS building complex. The 40 ft high bag house will cover a 50 ft by 20 ft area.

2.4.6.6 Seed

The seed handling building will house the hammermill, screen, and seed injector lock hopper system. The building will be 20 ft by 30 ft with an elevation of 24 ft. Primary storage will be external to the building in two storage silos of 500-ton capacity each.

2.4.6.7 Cryogenic

The cryogenic systems building for the air separation unit (ASU) and the SCM cooling system will house the main air separation plant compressors, blend air compressor, vacuum pumps, auxiliary equipment, instruments, controls, and the liquid helium storage dewar. The cold boxes and columns for the (ASU) liquid oxygen storage, and liquid nitrogen storage will all be located outside and adjacent to the building. The building size will be 75 ft by 40 ft. A 20-ton house crane will be included in the building for erection and service requirements of the installed heavy equipment. The portion (40 ft x 40 ft) of the building adjacent to the SCM will be 50 ft in height so that the liquid helium dewar can be placed at a high enough elevation to produce as least one atmosphere of gravity head against the SCM and eliminate pumping costs and reduce the length of the transfer piping to minimize heat losses. The remainder of the structure will be 24 ft in height.

2.4.6.8 Water Treatment

A small building for water treatment of final discharge wastes from slag handling, bottom ash sluicing, boiler blowdown, demineralizer regeneration, and plant washdown is envisioned to provide acceptable quality of water for recycling or eventual discharge into the Yellowstone River. The building would house filters for suspended solids removal and treatment chemicals to restore the proper chemical balance. The 40 ft by 33 ft building will be 24 ft in height.

2.4.6.9 Auxiliary Equipment

An auxiliary equipment building will be needed to house the service and instrument air compressor, injection air compressor, lube oil coolers, secondary cooling water systems, and other related equipment for operation of the facility. The 50 ft by 60 ft building will be an integral part of the other support related structures and be 24 ft in height.

2.4.6.10 Particulate Control Device

The 50 ft by 100 ft structure will be elevated to accommodate seed and fly ash removal at the ground level; the total height will be determined during the conceptual design phase. An adjacent silo will accept fly ash material on an interim basis for off-site removal.

2.4.6.11 Stack

The reinforced concrete stack will be the tallest structure of the complex at an estimated height of 250 ft. The minimum height required will be 200 ft to clear adjacent building structures and the final height will be determined by computer dispersion modeling of the exhaust. An inner steel liner will carry the cleaned HRSR exhaust gas. Sampling stations and platforms will be provided as well as exterior hazard warning lights in accordance with FAA requirements.

2.4.6.12 Maintenance

A maintenance building to handle specialty maintenance procedures on MHD system components will be located adjacent to the MHD building. An

instrument shop and an area for other routine maintenance will also be in this building. A 20-ton house crane will be included in the 50 ft by 80 ft by 24 ft high building.

2.4.6.13 Warehouse

A warehouse storage area is anticipated for additional storage or warehousing of specific MHD component materials as well as maintenance items for the other support equipment. Some operational materials may also be stored in this 40 ft by 40 ft building which is 24 ft in height.

2.4.6.14 Administration

An administrative building would house the normal office functions in addition to plant supervisory personnel, engineering staff, visitors, lunch room, men's and women's locker rooms, and toilet facilities. A septic tank and leach field will be used to dispose of the sanitary wastes as the plant site does not have access to the city's sewer system. The 40 ft by 80 ft structure would be 24 ft in height and have adjacent parking areas.

A designated operations area of 20 ft by 40 ft in the administrative building will be used as a central location in the facility to dispatch operators to the various plant support areas. This room will also contain as many local area control microcomputers as is practical given distance and proximity requirements. A second floor above the operations room would allow additional room for instrument or control functions.

2.5 Modifications

This section addresses those modifications to the Corette plant that are necessary to allow retrofit of the ATS to the Corette. The primary ones are those at the main interfaces of steam, feedwater, control instrumentation and electrical power. These interfaces as well as several of a secondary nature will require careful design and integration into existing systems.

2.5.1 Steam and Feedwater

There are four major interface modifications to the existing Corette plant steam and feedwater systems. All of these modifications are anticipated to be in the main ground floor pipe alley. The first would be in the 14 in. diameter high pressure superheated steam supply to the turbine. The installation of a flow sensing device and the actual interface connection from the HRSR high pressure superheated steam are required.

The second area of modification will be in the 24 in. diameter cold reheat steam after it leaves the turbine. This will require a sensing device, flow control device and routing a cold reheat steamline to the HRSR. The third modification will be to the 22 in. diameter hot reheat line as it is routed to the intermediate stages of the turbine. This will require only the interface connection where hot reheat steam returns from the HRSR on its way to the turbine.

The final major modification will be to the feedwater heating system. The 10 in. feedwater line will be tapped for HRSR feedwater at a position after the

No. 5 feedwater heater. A flow sensing device and flow control device, for the HRSR and Corette feedwater flows and for the interface are anticipated in this modification.

There will be minor modifications to the Corette steam and condensate system which will be more appropriately detailed during subsequent design phases. These modifications will consist of the following: expansion of the 175 psig steamheating system, low pressure condensate and high pressure condensate return interfaces, and condensate makeup supplies for the ATS condensate storage tank.

2.5.2 Water Systems

The modifications to supply condensate to the MHD channel cooling water, inverter cooling water, bearing cooling water, chemical feed, and HRSR fill and wash pump systems have been identified in the previous section. Those modifications will be at a single interface connection located at an outlet on the existing condensate storage tank which will supply a new ATS condensate storage tank. A removable spool piece that could be connected to the city water supply is also considered necessary for this modification to allow an alternate supply of clean water to those systems during initial checkout and startup. A modification allowing use of the existing Corette intake structure for service water will be minimal as that intake pipe is not in use at present. A modification to the existing city water supply is planned for makeup to the potable water elevated break tank. That interface connection should consist primarily of extending the existing city water line.

A modification to the existing Corette plant fire protection system is required. This will be an extension of the perimeter system that is presently routed around the plant site.

2.5.3 Fuels

Coal and natural gas are available at the Corette plant. Modifications to both the coal and natural gas systems are necessary to permit usage of both sources. A major modification to the coal system will be required to provide an adequate supply of coal to the ATS. An interface at the existing coal reclaim tunnel or optionally along the No. 5 coal conveyor will require a major design modification to facilitate the diversion of sufficient coal quantities to support the operation of the ATS.

A modification to the regulated natural gas system will be required to provide pilot ignition and HRSR warm up gun fuel supplies. This interface will be a new gas supply pipeline connection immediately after the existing Heart Mountain Regulating Station.

2.5.4 Effluent

Any liquid wastes generated in the ATS will be directed to the water treatment plant where they will be reprocessed for recycling. If the flow balance does not allow all water to be recycled, a discharge to the Yellowstone River is anticipated. Other than physically routing the pipe for discharge, there should be no modifications to the existing system.

It is planned that the slag and bottom ash solid waste material will be sold for asphaltic material filler or transported to an off-site disposal area. There could be periods when some on-site storage would be necessary for a short time at the location of the present ash storage. No modifications would be required, but storage capacity would be limited due to land availability.

2.5.5 Control Instrumentation

Modifications to existing control methodology in the Corette plant will be required at two points. The first point will be in the existing control room where control lines will be added to and from the new supervisory computer. The computer will be installed in the existing control room to facilitate utility operator control.

The second point will be in the reheat steam and feedwater loops from the turbine. Flow diverting valves and control instrumentation are required at the locations where the ATS plant picks up reheat steam and feedwater. These valves are necessary in order to keep the reheat steam and feedwater flows to the two boilers at the same ratio as superheat steam is being generated.

2.5.6 Electrical Systems

There are no planned modifications to the electrical system of the Corette plant. Currently there is no electrical capacity available for the MHD retrofit; thus, the anticipated electrical system will be independent of existing MPC service except for a connection to the 100 KV ring bus at the

Plant Substation. This connection will not interfere with present MPC operations.

2.5.7 Site

Modifications to the site are minimal as the available area is generally open, level and been used previously for construction staging areas. A construction office building and oil storage building are presently on the site and will necessitate removal or relocation. Portions of existing drives, parking areas, or seeded lawn will require modifications to allow road building and construction facilities parking. Modifications also will be required to adapt the rail spur for bulk unloading of consumable materials; an additional rail spur will be required for construction deliveries.

The power supply and communication cables strung along the No. 5 coal conveyor support columns will have to be raised to allow adequate building clearance. These support columns will require additional study during the preliminary design phase as the present configuration would have some building interference with the columns.

Three pipelines have been identified for positive relocation requirements. These lines are the 36 in. yard drain with various catch basins, the 10 in. Corette bottom ash discharge to the ponds, and the oil separation discharge line to the Corette discharge structure. These can be relocated outside of the ATS perimeter to prevent interference during construction. A routing for the new discharge line from the water treatment plant will traverse open land and should require no modifications to the existing land.

2.6 Operational

In this section the operational considerations based upon the previously defined retrofit configuration will be discussed. This discussion is limited to unique or critical aspects of overall plant operation.

2.6.1 MHD Systems

The coal-fired combustor, MHD channel and diffuser will require thorough prestart-up operational checkouts. Operation of the other MHD systems, MHD support systems, and the Corette systems will be integrated into a startup procedure requiring approval from the Corette plant utility superintendent. Continuing MHD operation, as well as MHD shutdown procedures, will be coordinated and approved by the Corette plant utility superintendent.

Prior to ATS startup, the cooldown of the superconducting magnet to 4.1° K must be accomplished, as well as the establishment of the initial vacuum in the helium system, and recirculation of helium to maintain temperature requirements during operations.

The HRSR boiler and associated system will have a startup procedure independent of actual MHD operation. Natural gas warm up guns would be inserted and fired to preheat the boiler and provide thermal circulation to avoid excessive high temperature thermal stresses when the MHD power train is started up. Any generation of low grade steam during this time or during initial firing of the MHD power train would be fed into a turbine bypass system to avoid the problem of two varying grades of steam being fed to the

Corette turbine-generator. The turbine bypass systems would be designed as a separate system with the capability of addressing the superheat and reheat steam requirements of the turbine-generator during the startup operation. Both the turbine-generator manufacturer and HRSR supplier would require consultation during the preliminary design phase. When the quantity and quality of the HRSR superheated steam approaches that of the Corette boiler, the supervisory control would slowly integrate that steam into the turbine system while compensating for the Corette boiler steam load and adjusting to turbine requirements.

On the approval of the Corette plant utility superintendent the AC output switch from the inverter will be closed when the MHD electrical power generated is compatible with criteria established. A failure of the MHD power train, through planned relaying, can open the AC output switch and isolate the inverter from any backfeed.

The Corette plant utility superintendent will have the ultimate control of both the Corette plant and ATS through the supervisory computer control system. The supervisory computer not only interfaces between the two units but also is the master control for all of the local subsystem control microcomputers. The Data Acquisition System is a subsystem of the supervisory control system and as such is always operational during ATS facility operation.

2.6.2 Support Systems

The filling of the ATS coal bunkers is to be coordinated with the Corette plant coal bunker filling operations. Prepared coal can be available for

startup of the MHD power train by prior activation of the coal preparation system. Coal for bunker refilling activities will require specific coordination, and the Corette plant utility superintendent would have the ultimate responsibility for fuel distribution.

After obtaining a bulk supply of seed material the operational aspects of feeding the seed to the MHD power train would be accomplished by a sequential system startup procedure.

The oxidizer system which includes the manufacturer of liquid oxygen and liquid nitrogen can be started and operated independently of the other systems. Sufficient quantities of liquid oxygen and nitrogen to support the startups of the SCM and coal preparation areas can be manufactured prior to these startup activities. Oxygen requirements for normal MHD power train operation will be supplied from the continuing operation of the air separation unit which will also supply the gaseous nitrogen for coal drying and inerting.

Both liquid and solid effluent handling systems will require coordination for disposable requirements to prevent operational conflicts between the two plants.

The auxiliary systems that have a direct or secondary interface with the MHD power train or its auxiliary equipment are: 1) the water systems; 2) auxiliary fuel; 3) compressed air; and 4) heating/ventilating requirements. All of these systems either obtain their input from the existing Corette plant or operate independently within the ATS facility. As

such, these systems operation will be integrated into startup, transient or normal operations by use of the supervisory control system.

The particulate control device would be activated and operate in concert with the HRSR as it is brought up to operating conditions. Disposal of fly ash will require total plant coordination to prevent operational interference.

The substation and transmission lines will be energized and require no other action to provide the power requirements as necessary for operation.

2.6.3 Interface Systems

As long as the Corette plant is operating, the steam, feedwater, and water systems will be operational and require minimum coordination to interface with the ATS, when operation is accomplished with the supervisory computer control system.

Instrumentation and controls are effectively managed by the supervisory control system. The electrical system is operational once the main switch from the 100 KV ring bus is energized and should require no additional operational adjustment.

The buildings and structures for the ATS facility can remain an autonomous island adjacent to the existing Corette plant. Access will not be restricted to the ATS but it is expected that there will be minimum interaction except for the supervisory control.

2.6.4 System Integration

As discussed in previous sections, the true integration of the ATS with the Corette plant is through the interfaces of the steam, feedwater, water, and fuel systems. The use of supervisory computer control in the instrumentation and control systems will successfully integrate the two operating systems, especially when ultimate responsibility is given to the Corette plant utility superintendent. Starting and loading of the various ATS systems will require coordination between the plants to alleviate unnecessary starts or delays in the operation of the ATS. High motor starting loads are especially susceptible to power grid operating conditions.

2.6.5 Special Conditions

There are only a few special operational conditions that require consideration beyond those of a normal coal-fired power generating plant.

One is that to prevent any possibility of spontaneous ignition of dried and pulverized coal, the prepared coal storage bin should be completely run empty at the conclusion of MHD power train operations. Another would be the general awareness that liquid oxygen is an impact sensitivity material and if brought into contact with hydrocarbon compounds can be highly dangerous when improperly handled. The final caution is that there should be restricted access in the highly energized field generated around the SCM.

Close attention must be given to the quantity and quality of the two high-pressure superheated steam supplies. The supervisory control will function to minimize these differences but operator awareness could prevent many operational problems from developing into major control excursions.

Various tests, as well as maintenance and inspection shutdowns, may be expected at a greater frequency than at a conventional steam plant. These activities will be coordinated through, and controlled by the Corette plant utility superintendent.

3.0 ENVIRONMENTAL REQUIREMENTS

Retrofit of an existing power plant with an MHD system will require that applicable environmental regulations be followed. Depending on local and state regulations, and the ownership of the MHD system (federal or private) certain siting, air quality, water quality, solid waste, and health and safety regulations will have to be met. These regulations are summarized in Table 3-1. In the following text the environmental considerations for the following MHD retrofit scenarios are discussed:

- MHD retrofit of the MPC Corette Plant, Billings, Montana; DOE ownership of new hardware;
- MHD retrofit of any coal-fired power plant in Montana; private ownership of new hardware; and
- MHD retrofit of a coal-fired power plant anywhere in the country; private ownership of new hardware.
- MHD retrofit of a coal-fired power plant anywhere in the country; DOE ownership of new hardware. This scenario is identical to that described for private ownership of new hardware.

3.1 Site Requirements/NEPA-MEPA

3.1.1 Montana Regulations

Figure 3-1 summarizes the Major Facilities Siting Act, MEPA, and NEPA process described below. The procedural requirements of the Montana Major Facilities Siting Act (MMFSA), 75-20-101, *et. seq.* M.C.A., will not apply to a federally

TITLE	LAW	RESPONSIBLE AGENCY	ACTIVITY									
			Federal EIS	State EIS	Siting	Water Appropriation	Water Discharge	Dredge and Fill	Construction	Solid Waste	Air Emissions	Operation
National Environmental Policy Act (NEPA)	42 U.S.C. 4321 *et*. *seq*.	DOE (if federally owned)	X									
Montana Environmental Policy Act (MEPA)	75-1-101 *et*. *seq*. M.L.A.	DNRC or DHES		X								
Montana Major Facilities Siting Act (MMFSA)	75-20-101 *et*. *seq*. M.L.A.	DNRC			X							
Montana Water Use Act (MWUA)	85-2-301 thru 314. M.L.A.	DNRC				X						
Montana Water Quality Act (MWQA)	75-5-101 *et*. *seq*. M.L.A.	DHES					X		X			
Federal Clean Water Act (FCWA)	33 U.S.C. 1344 Section 401	DHES for EPA					X		X			
Federal Clean Water Act (FCWA)	33 U.S.C. 1344, Section 404	COE for EPA						X	X			
Montana Solid Waste Management Act (includes hazardous waste)	74-10-201 *et*. *seq*. M.C.A.	DHES							X	X		
Federal Resource Conservation and Recovery Act	42 U.S.C. 6901 *et*. *seq*.	DHES and EPA							X	X		
Montana Clean Air Act	75-2-101 *et*. *seq*. M.C.A.	DHES							X		X	
Federal Clean Air Act	42 U.S.C. 1857 *et*. *seq*.	DHES for EPA							X		X	
Federal Occupational Safety and Health Act	29 U.S.C. 688 *et*. *seq*.	OSHA							X			X

Table 3-1 -- Major Environmental Laws Governing an MHD Retrofit of an Existing Power Plant in Montana

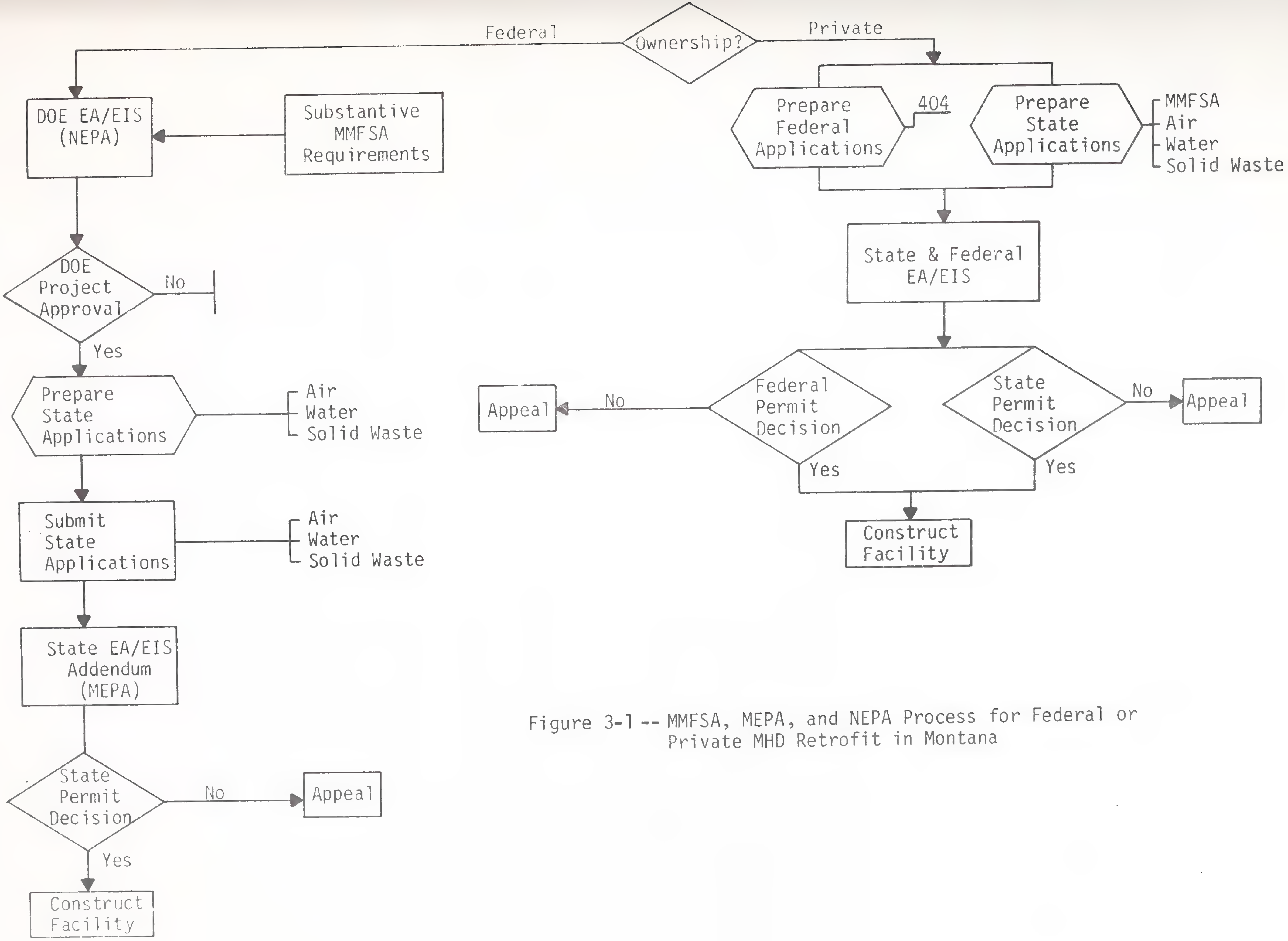


Figure 3-1 -- MMFSA, MEPA, and NEPA Process for Federal or Private MHD Retrofit in Montana

owned retrofit of the MPC Corette Plant, Billings, Montana. The MMFSA, Section 75-20-202(1) M.C.A., specifically exempts "...any aspect of a facility over which an agency of the federal government has exclusive jurisdiction." However, there is a question of whether or not substantive requirements of the act will have to be met. The question of meeting substantive requirements of the act has been raised by a recent ruling by federal Judge James Battin that the Bonneville Power Administration must meet the substantive requirements of the act for a transmission facility being built in Montana. This ruling was based on a requirement of federal law that federal facilities must meet all state and local regulations. The actual substantive requirements that would have to be met would be determined by the Montana Board of Natural Resources and Conservation (DNRC). There would be a possibility of waivers for certain requirements as, under certain conditions, the board may adopt reasonable rules establishing exemptions from the MMFSA (75-20-202(3) M.C.A.).

The MMFSA will apply to a privately owned MHD retrofit of an existing power plant in Montana. MMFSA parts that support this conclusion include:

- 5-20-104(1) "Addition thereto" means the installation of new machinery and equipment which would significantly change the conditions under which the facility is operated; and
- 75-20-104(10a) "Facility" means ...each plant, unit, or other facility and associated facilities designed for or capable of: (i) generating 50 megawatts of electricity or more or an addition thereto (except pollution control facilities approved by the Department of Health and Environmental Sciences added to an existing plant) having an estimated cost in excess of 10 million.

For a privately owned facility both the procedural and substantive requirements of the MMFSA would have to be met. The applicable requirements of the MMFSA include:

- Inclusion in a ten year plan;
- Notice of intent to file an application;
- Environmental and Engineering studies;
- Application for a certificate which includes results of the environmental and engineering studies;
- Payment of an application fee;
- DNRC study of application and report to the Board (DNRC EIS);
- Board of Natural Resources and Conservation hearing; and
- Board of Natural Resources and Conservation decision to grant or deny certification.

Certain requirements of the MMFSA could be waived by the Board for an MHD retrofit pursuant to 75-20-202(3) M.C.A.

The Montana Environmental Policy Act (MEPA) 75-1-01 et. seq. M.C.A. will apply to any MHD retrofit of an existing power plant in Montana. If the retrofit will be federally owned then the probable state lead agency will be the Department of Health and Environmental Sciences (DHES) as this agency will be responsible for granting air, water, and waste disposal permits. Application of MEPA in this scenario would require DHES to perform an Environmental Assessment (EA) or to write an Environmental Impact Statement on the effects of granting the required permits. Further discussion of the air, water, and waste disposal permits is found in later sections of this

report. If a federal EIS has been written on the project then MEPA allows the state to incorporate the federal EIS by reference; thus allowing the state EIS to take the form of an addendum.

If the retrofit will be privately owned then DNRC will be the lead state agency due to the umbrella effect of the MMFSA. MEPA would require DNRC to write an EA or EIS on the effects of granting a certificate of Public Need and Environmental Compatibility to the utility. If a federal EIS has been written then DNRC would be able to prepare an addendum to fulfill its MEPA requirements.

The EIS must contain the same type of information no matter which state agency prepares it. The EIS must:

- Describe the environmental impact of the proposed action (action taken by the state agency such as granting the permit);
- Describe any adverse environmental effects which cannot be avoided should the action be taken;
- Describe alternatives to the proposed action;
- Describe the relationship between local short-term uses of man's environment and maintenance and enhancement of long-term productivity; and
- Describe any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.

3.1.2 Federal Regulations

There are no national laws or regulations governing the siting of MHD retrofits of existing power plants. However, the identification and comparison of alternatives as required by the National Environmental Policy Act (NEPA) 42 U.S.C. 4321 et.seq. essentially requires a siting study.

NEPA requires that a federal agency proposing a specific action perform an environmental assessment (EA) to determine if the effects of the proposed action will have significant impact on the human environment. If a positive determination is made then the federal agency must prepare an Environmental Impact Statement (EIS). The State EIS format and content described earlier were patterned after the federal requirements; therefore, a federal EIS will contain the same information as described for the State EIS.

There are two MHD retrofit scenarios that would require a federal EIS. If the proposed retrofit of the MPC Corette Plant in Billings will be federally owned then DOE will be required to perform a NEPA EA and/or EIS. A privately owned retrofit of an existing power plant in Montana may not require a federal EA or EIA as all major permits are obtained from the State DNRC-DHES. A federal EIS would be necessary in this case only if one of the minor federal permit (such as the Corp of Engineers 404 dredge and fill permit) environmental assessments found that a significant impact to the human environment would occur as a result of the granting of the permit. A federal EA and/or EIS would be required in other states for a privately owned MHD retrofit if a state did not operate federally approved air and water quality programs. In a state where the Environmental Protection Agency (EPA)

operates the air and water quality permit system then EPA will be responsible for meeting the EIS requirements of NEPA. This process is shown in Figure 3-2.

3.2 Air Quality

An MHD retrofit to any facility whether owned privately or by DOE must comply with three different, but related, types of air quality regulations. These are the New Source Performance Standards (NSPS) regulating point sources, State and Federal Ambient Air Quality Standards, and Prevention of Significant Deterioration (PSD) regulations. These three sets of air quality regulations are discussed in the following text in regard to their application to the design of an MHD retrofit facility, particularly the Corette case.

All air quality permitting for a major facility in Montana, such as the MHD retrofit, is administered through the Department of Health and Environmental Sciences - Air Quality Bureau. Permitting for both federal and State of Montana requirements is handled jointly since Montana has EPA approved programs for administering all permitting required by the Federal Clean Air Act. Yellowstone County's air quality regulations are not applicable to major facilities such as the proposed MHD retrofit. Consequently, only State of Montana and federal requirements will be discussed.

3.2.1 New Source Performance Standards

One goal of an MHD retrofit, whether owned by the Government or a utility, is to demonstrate that the technology complies with the emission control

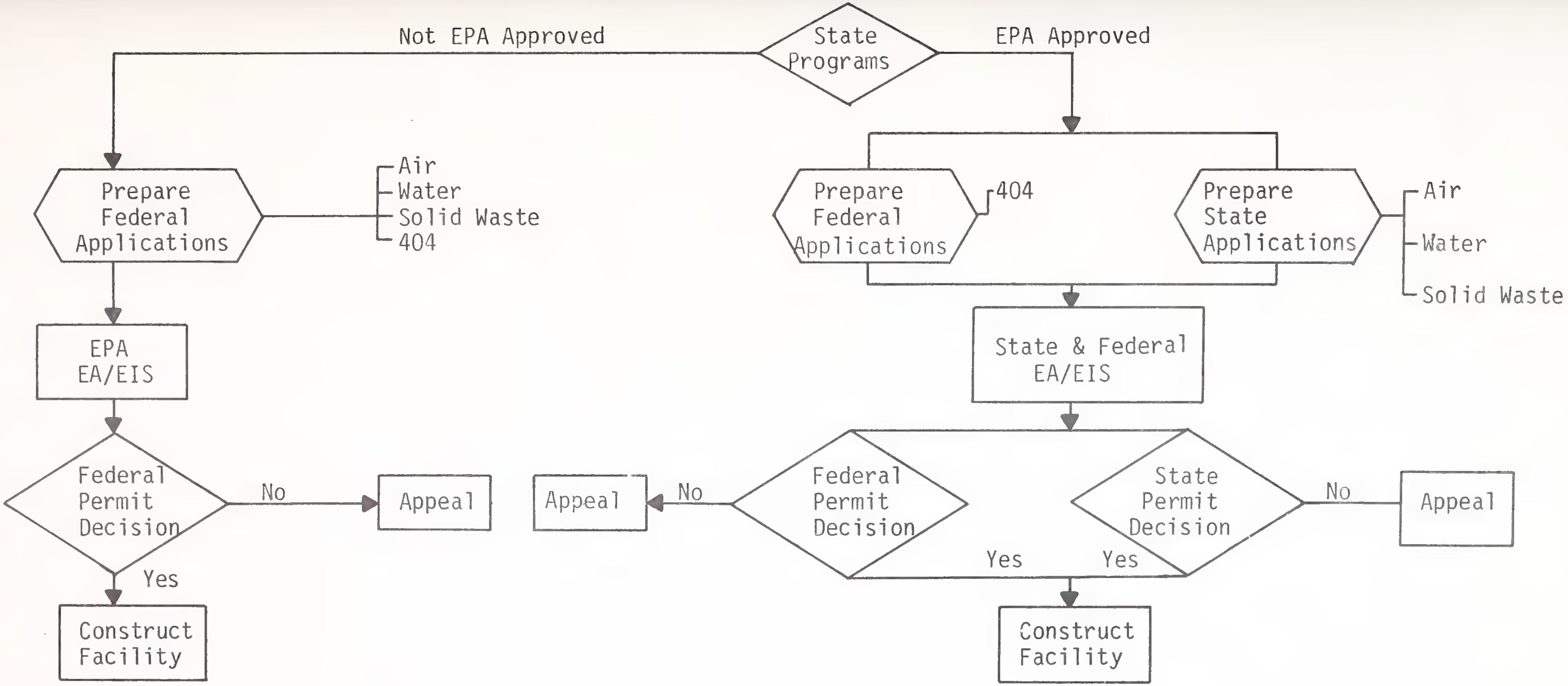


Figure 3-2 -- NEPA Process in States Other Than Montana for a Privately Owned Retrofit

regulations for coal-fired electric utility units. These regulations, shown in Table 3-2, apply to units constructed for the purpose of supplying more than one-third of its "potential electric output capacity" (defined as 33% of the maximum design heat input capacity) and more than 25 MW_e output to any utility power distribution system for sale. The Corette retrofit clearly meets these criteria thus the design considerations for emission control are based upon the standards in Table 3-2.

The NSPS for particulates will require either a highly efficient electrostatic precipitator (ESP) or baghouse. Based on the material balance of ash, slag, and potassium seed material for the MHD process stream the collection efficiency of either device must be a minimum of 99.5% at the expected inlet loading of 5,000 lb/hour. This requirement is based on slag rejection rate accomplishing 85% ash removal at the combustor with about half of the remaining ash, slag, and seed being removed in the radiant furnace and convective sections.

Based on either requirements for Best Available Control Technology (BACT) or Lowest Achievable Emission Rate (LAER) mandated for new facilities by federal and Montana regulations, fabric filtration control is the recommended method based on the current state of the art. High collection efficiency over the entire range of particle size and generally lower cost than electrostatic precipitators makes this option appear more favorable. Another disadvantage of using an ESP for this retrofit facility is uncertainty in both the chemical characteristics and size distribution of particulate which must be controlled. Detailed knowledge of these chemical and physical parameters are

TABLE 3-2

NEW SOURCE PERFORMANCE STANDARDS (AIR) FOR ELECTRIC UTILITY STEAM GENERATING UNITS (44 FR 33580)

Emissions Limits for Coal-Fired Units

Particulates

13 ng/J (0.03 lb./MBtu)

20% opacity (except for one 6-minute period per hour of not more than 27% opacity)

SO_2

520 ng/J (1.2 lb./MBtu)*

90% reduction except 70% reduction when emissions are less than 26 ng/J (0.6 lb./MBtu)*

NO_x

Subbituminous coal, shale oil, fuel derived from coal: 210 ng/J (0.5 lb./MBtu)*

*30-day rolling average

essential to the design and sizing of an ESP. The proposed facility could provide an opportunity for obtaining much of this data which is not currently available from existing MHD test facilities.

The NSPS for SO_2 requires 90% control of potential SO_2 emissions based on the sulfur content of the coal being used. An upper limit of 1.2 lb SO_2 per 10^6 Btu is allowed, but the requirement is relaxed to 70% control if emissions are less than 0.6 lb per 10^6 BTU as indicated in Table 3-2. For the reference Rosebud coal being used for design purposes, 70% control of sulfur will satisfy the NSPS requirements, limiting potential emissions to 0.6 lb SO^2 per 10^6 BTU. This requirement should be easily met by using the appropriate amount of K_2CO_3. For once through seed usage (no recycling or regeneration) a minimum of 30% of the necessary potassium should be K_2CO_3 to achieve the 70% reduction and 0.6 lb per 10^6 BTU emission requirements. The remaining potassium can be added as some less expensive form such as K_2SO_4.

For any general case for MHD requiring more stringent control of SO_2, the proportion of K_2CO_3 can be increased with virtually total elimination of SO_2 emissions, if deemed necessary. This feature of MHD is unique and can play an important role in the siting of an MHD facility, particularly in areas where regulatory constraints severely limit the allowable emission of SO_2.

The NO_x emission requirement of 0.5 lb. per 10^6 BTU must be met by fuel rich initial combustion stoichiometry ($\emptyset$ = .85) at the MHD combustor followed

by secondary combustion in the radiant furnace at a lower temperature with sufficient residence time at appropriate temperatures to allow relaxation of NO_x to acceptable NSPS levels.

To meet the NSPS described in this section maximum emissions from the Corette MHD retrofit will be limited to the following:

Particulates	26 lb/hour (.03 lb/10^6 BTU)
SO_2	514 lb/hour (.6 lb/10^6 BTU)
NO_x	428 lb/hour (.5 lb/10^6 BTU)

These values can be used in dispersion models appropriate to the plant setting to determine if all ambient air quality standards and prevention of significant deterioration (PSD) regulations are being met at maximum allowable emission rates. PSD and ambient regulations and their possible influence on emission control are discussed in the following Sections 3.2.2 and 3.2.3.

3.2.2 Ambient Air Quality Standards

Federal Ambient Air Quality Standards are shown in Table 3-3 and Montana Ambient Air Quality Standards are shown in Table 3-4. Notwithstanding the NSPS discussed in Section 3.2.1 and the PSD increments discussed in Section 3.2.3, these ambient concentrations cannot be exceeded. The Federal standards apply to facilities anywhere in the country. State standards vary considerably depending on the locality but, in all cases are at least as stringent as the Federal standard.

TABLE 3-3

NATIONAL AMBIENT AIR QUALITY STANDARDS[a]

	Primary Standard	Secondary Standard
Particulate		
24-hour average	260 g/m^3[b]	150 g/m^3[b]
Annual geometric mean	75 g/m^3	60 g/m^3
Sulfur Dioxide		
3-hour average	- -	0.5 ppm (1300 g/m^3)[b]
24-hour average	0.14 ppm (365 g/m^3)[b]	- -
Annual average	0.03 ppm (80 g/m^3)	- -
Carbon Monoxide		
1-hour average	35 ppm (40 mg/m^3)[b]	35 ppm
8-hour average	9 ppm (10 mg/m^3)[b]	9 ppm
Ozone		
1-hour average	0.12 ppm (235 g/m^3)[b,c]	0.12 ppm
Nitrogen Dioxide		
Annual average	0.05 ppm (100 g/m^3)	0.05 ppm
Lead		
Calendar quarter	1.5 g/m^3	1.5 g/m^3
Hydrocarbons		
3-hour concentration	0.24 ppm (160 g/m^3)[d,b]	- -

a. 40 CFR Part 50
b. Not to be exceeded more than once per year
c. 44 FR 8202
d. Guideline only

TABLE 3-4

MONTANA AMBIENT AIR QUALITY STANDARDS

(Montana Department of Health and Environmental Sciences,
Air Quality Rules, 1982)

CO	
8-hour average	9 ppm*
Hourly average	23 ppm*
H_2S	
Hourly average	.05 ppm*
Lead	
Calendar quarter average	1.5 g/m^3
NO_2	
Hourly average	0.30 ppm*
Annual average	0.05 ppm
Ozone	
Hourly average	0.10 ppm*
Settled Particulate Matter	
30-day average	10 g/m^2
SO_2	
Hourly average	0.50 ppm**
24-hour average	0.10 ppm*
Annual average	0.02 ppm
Suspended Particulate Matter	
24-hour average	200 g/m^3*
Annual average	75 g/m^3

Visibility

Annual average particle scattering coefficient of 3 x 10^{-5}/m.
Applicable only to designated PSD Class I areas.

*Not to be exceeded more than once per year.
**Not to be exceeded more than 18 times in any 12 consecutive months.

Whether these ambient standards or the PSD increments in Section 3.2.3 are limiting constraints depend on the specific locality of the proposed facility and the existing baseline ambient air quality in the region. In general, PSD increments are the limiting factors for particulates and SO_2 unless baseline concentrations are near, but not exceeding, the ambient standard.

If Federal ambient standards are already exceeded, the area is designated a non-attainment area for specific pollutants. In such non-attainment areas, new sources would not be allowed unless a corresponding decrease in the pollutant of concern is achieved in the area. This is referred to as emission offset and the applicant for a permit must provide for reduction in existing emissions of the non-attainment pollutant in the area sufficient to achieve an improvement in ambient concentrations of that pollutant, even after the new source is in operation.

3.2.3 Prevention of Significant Deterioration (PSD)

The Federal Clean Air Act sets PSD increments for SO_2 and particulates as shown in Table 3-5. These increments are measured against a baseline determined by the date of the first PSD permit application in the air quality control region.

Pollutant category of the proposed facility will be that of "major source" for both SO_2 and particulate. "Major source" is defined for these purposes as having potential emissions exceeding 40 tons per year of SO_2 or 25 tons per year of particulate.

TABLE 3.5

PREVENTION OF SIGNIFICANT DETERIORATION IN AIR QUALITY: ALLOWABLE INCREMENTS IN ug/m^3 (43 FR 26405)

Pollutant*	Class I	Class II	Class III
Particulates:	ug/m(3)		
Annual geometric mean	5	19	37
24-hour average	10	37	75
SO_2			
Annual arithmetic mean	2	20	40
24-hour average	5	91	182
3-hour maximum	25	512	700

*All values other than annual averages may be exceeded once per year.

*No pollutant concentrations may exceed national ambient air quality standards.

Once a source is determined to be a major source for any pollutant for which ambient standards currently are being met, PSD review applies to all pollutants which will be emitted by the source. These requirements include, as a rule, one year of pre-application monitoring of ambient air quality, and an air quality impact analysis based on monitoring or modeling, to determine the extent of anticipated impacts of the facility on ambient air quality. In addition, BACT would be required for all pollutants.

If the results of the PSD review and modeling warrant, control requirements more stringent than the NSPS discussed in Section 3.2.1 could be mandated. As mentioned previously, the MHD process has the capability of meeting virtually any SO_2 control requirement particularly when low-sulfur coal is used.

The existing Corette facility is located in an area where ambient SO_2 concentrations are near or exceed ambient standards. It is possible that the area could be designated a non-attainment area for SO_2. If this occurs, nearly total removal of SO_2 emissions could be required. Even if the area is not so designated, very little increment remains between baseline concentrations and the allowable ambient concentrations.

SO_2 appears to be the only ambient standard which will significantly influence design requirements for an MHD retrofit to the Corette facility. The MHD process as designed should meet the Class II PSD increments for particulate and the ambient NO_x Standards when operating at the maximum allowable NSPS mission rates described in Section 3.2.1. A detailed modeling study will be required as part of the PSD permit and air pollution discharge permit to demonstrate quantitative compliance with these regulations.

The general air quality permit process which must be followed is shown in Figure 3-3. If submitted under the Montana Major Facility Siting Act, all applications will be through DNRC to the DHES. The indicated permits will be submitted as an integral part of the application to DNRC.

3.3 Water Quality

3.3.1 Montana Regulations

In Montana, the ownership (federal or private) of an MHD retrofit to an existing power plant would not affect the applicability of the water pollution control regulations; therefore, the following discussion is applicable to a federally or privately owned retrofit of the Corette plant in Billings, Montana or a privately owned retrofit of any other power plant in the State.

The Montana Department of Health and Environmental Sciences (DHES) administers the Montana Pollution Discharge Elimination System (MPDES). In order for an entity (private or public) to discharge liquid wastes into surface waters of the state, the entity must obtain a MPDES permit from DHES. Information required in the permit application includes:

- Background flow and quality information on the receiving stream;
- Quality and flow information on the discharge;
- Process and treatment information; and
- Map(s) of point(s) of discharge.

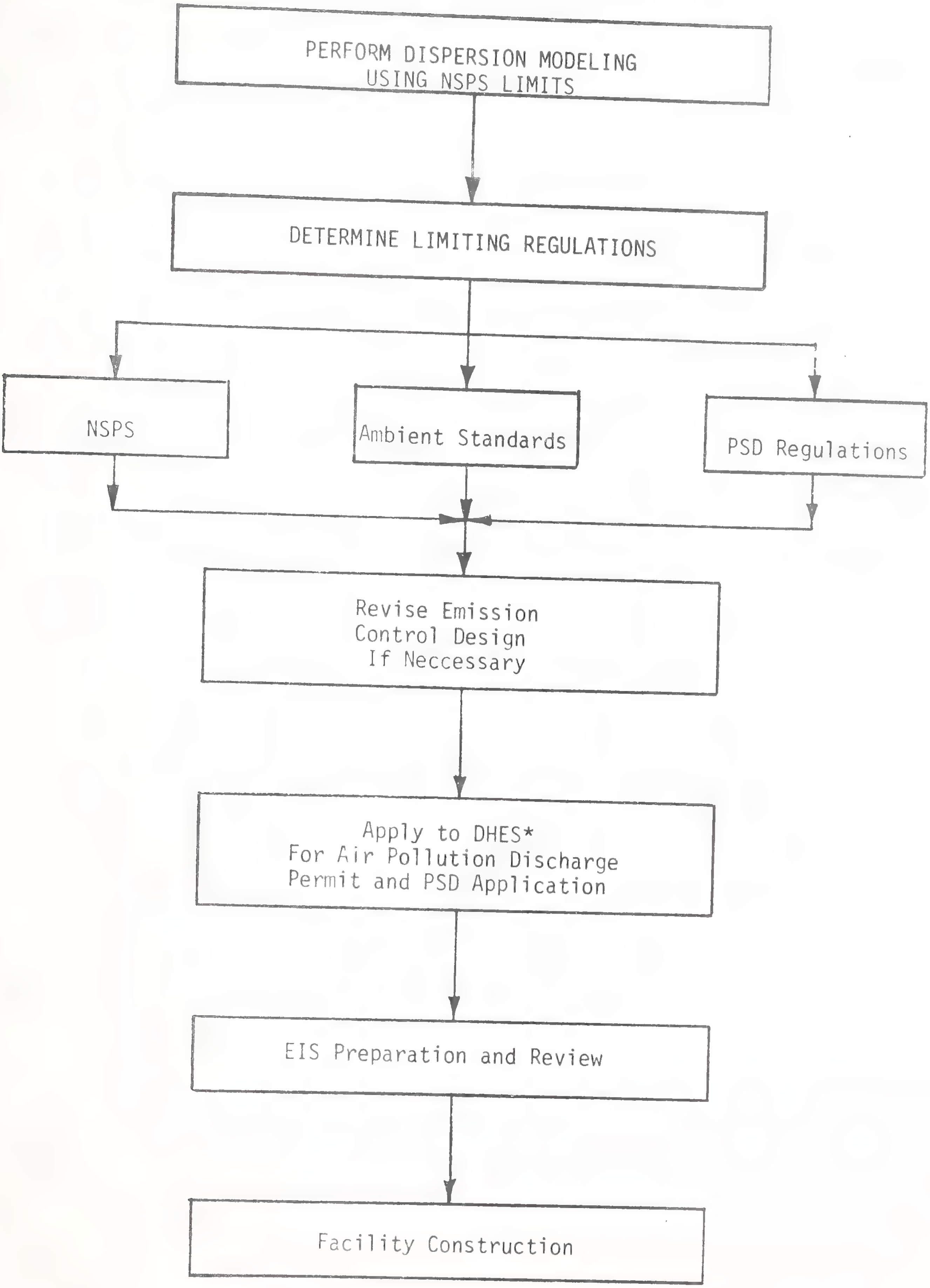

PERFORM DISPERSION MODELING
USING NSPS LIMITS
DETERMINE LIMITING REGULATIONS
NSPS
Ambient Standards
PSD Regulations
Revise Emission
Control Design
If Neccessary
Apply to DHES*
For Air Pollution Discharge
Permit and PSD Application
EIS Preparation and Review
Facility Construction

Figure 3-3 -- Air Quality Permitting Process

*May be formally submitted to DNRC if the Major Facility Siting Act is followed, DHES will review in any case.

The MPDES was established by the Montana Water Quality Act 75 -5-101 et.seq. M.C.A. and the administrative rules are found at 16.20.901-919, A.R.M.

When a currently operating facility, such as the Corette plant, is discharging under an existing MPDES permit then the addition of the MHD retrofit will require either a brand new permit, if a new discharge will occur, or a permit modification, if the waste water from the new retrofit facility will be handled by the existing waste water handling system. Differences between these cases are mostly procedural as the data required for a permit modification is similar to that required for a new permit. The Corette water and waste handling systems are operating at capacity now; therefore, a retrofit of the Corette plant will require new discharge permits for any releases to the Yellowstone River (see Section 2.2.4). Existing limitations on the Corette discharge permit indicate that the MHD retrofit may have to remove all heat from cooling water releases. The MPDES process is summarized in Figure 3-4.

Since Montana operates an EPA approved water quality program, DHES issues the Section 401 (of the Federal Clean Water Act) permit. This permit is only issued if the project requires other federal permits and will discharge into navigable waters. The permit is a certification by DHES that the discharge will comply with the applicable provisions of the Federal Clean Water Act, Sections 301, 302, 303, 306, and 307. Information needs on the application are similar to those for the MPDES permit.

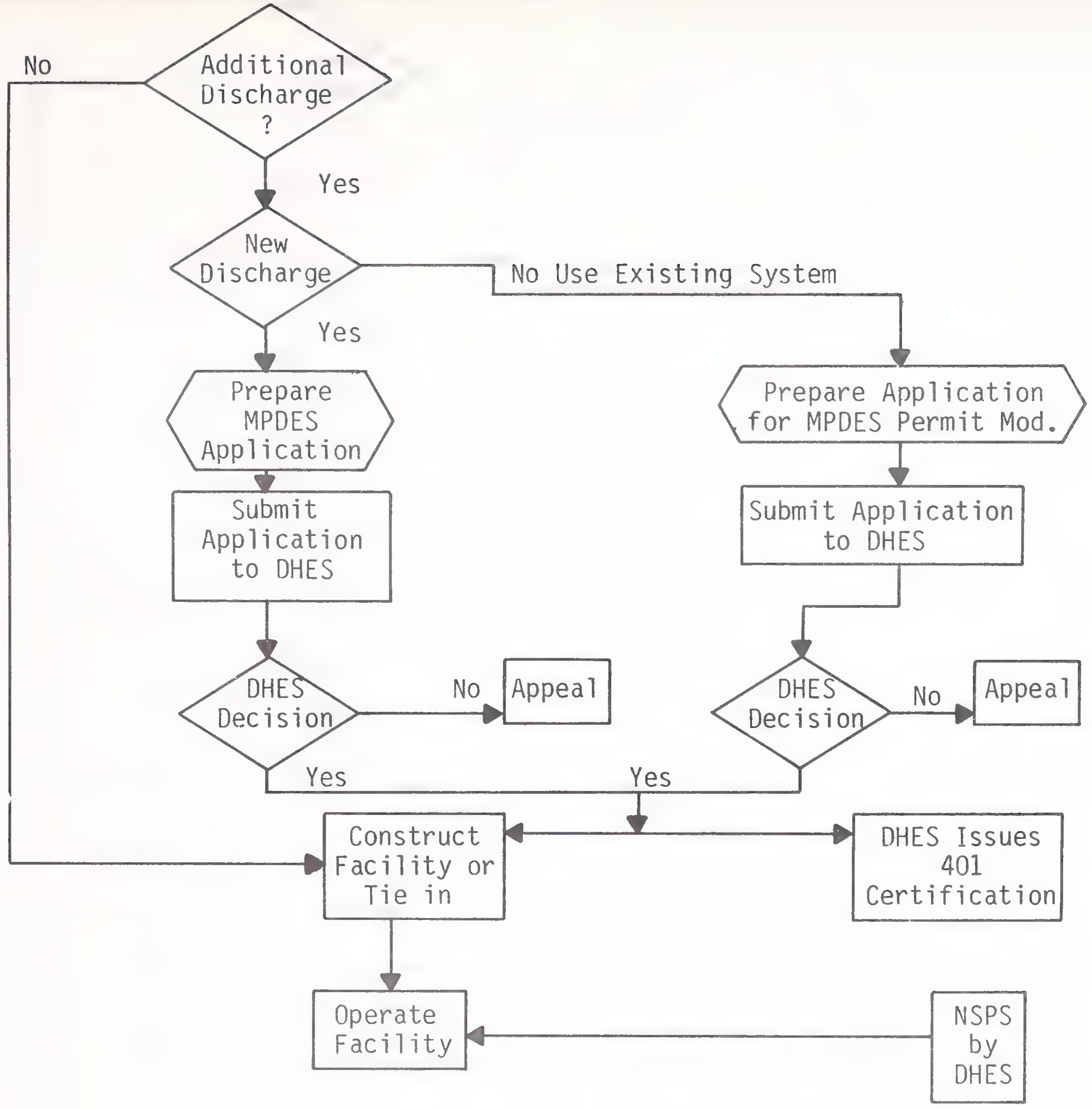

Additional Discharge ?
No
Yes
New Discharge
No Use Existing System
Yes
Prepare MPDES Application
Prepare Application for MPDES Permit Mod.
Submit Application to DHES
Submit Application to DHES
DHES Decision
No
Appeal
DHES Decision
No
Appeal
Yes
Yes
Construct Facility or Tie in
DHES Issues 401 Certification
Operate Facility
NSPS by DHES

Figure 3-4 -- Process Diagram For Application Of MPDES And NSPS Regulations For Water For An MHD Retrofit Of An Existing Power Plant In Montana

A permit to appropriate water, obtained from the Montana Department of Natural Resources and Conservation, may be required for an MHD retrofit of an existing plant (Montana Water Use Act 85-2-301- et.seq.). An appropriation permit will only be required if the sum of the water required to operate the MHD addition and the water required to operate the existing plant will exceed the currently held water appropriation. According to engineering estimates concerning water for an MHD retrofit to the Corette Plant in Billings the sum of the additional water needs plus existing water needs will not exceed the present MPC appropriation. (See Sections 2.2.4 and 2.3.3). The appropriation process is also summarized in Figure 3-4.

The Montana DHES, Water Quality Bureau, enforces the national New Source Performance Standards (NSPS) for water. The standards for steam-electric generating units, found in 40 CFR, Parts 125 and 423, dictate the allowable levels of certain parameters in the waste streams. Limitations are listed for effluents, once-through cooling water and cooling tower blowdown, area run-off, and pre-treatment for sewer system releases. If a new coal preparation plant is constructed as part of the new facility, then the New Source Performance Standards (found in 40 CFR Part 434.20) will control levels of certain parameters in the runoff from the facility.

An authorization for Short-Term Exemption From Surface Water Quality Standards, obtained from DHES, is required when there will be instream construction activities that cause turbidity standards for the stream to be exceeded. The MHD retrofit to the Corette Plant in Billings will probably not need this authorization as current design requirements discussed in this document do not indicate the need for construction of a new intake structure, (see Section 2.3.3).

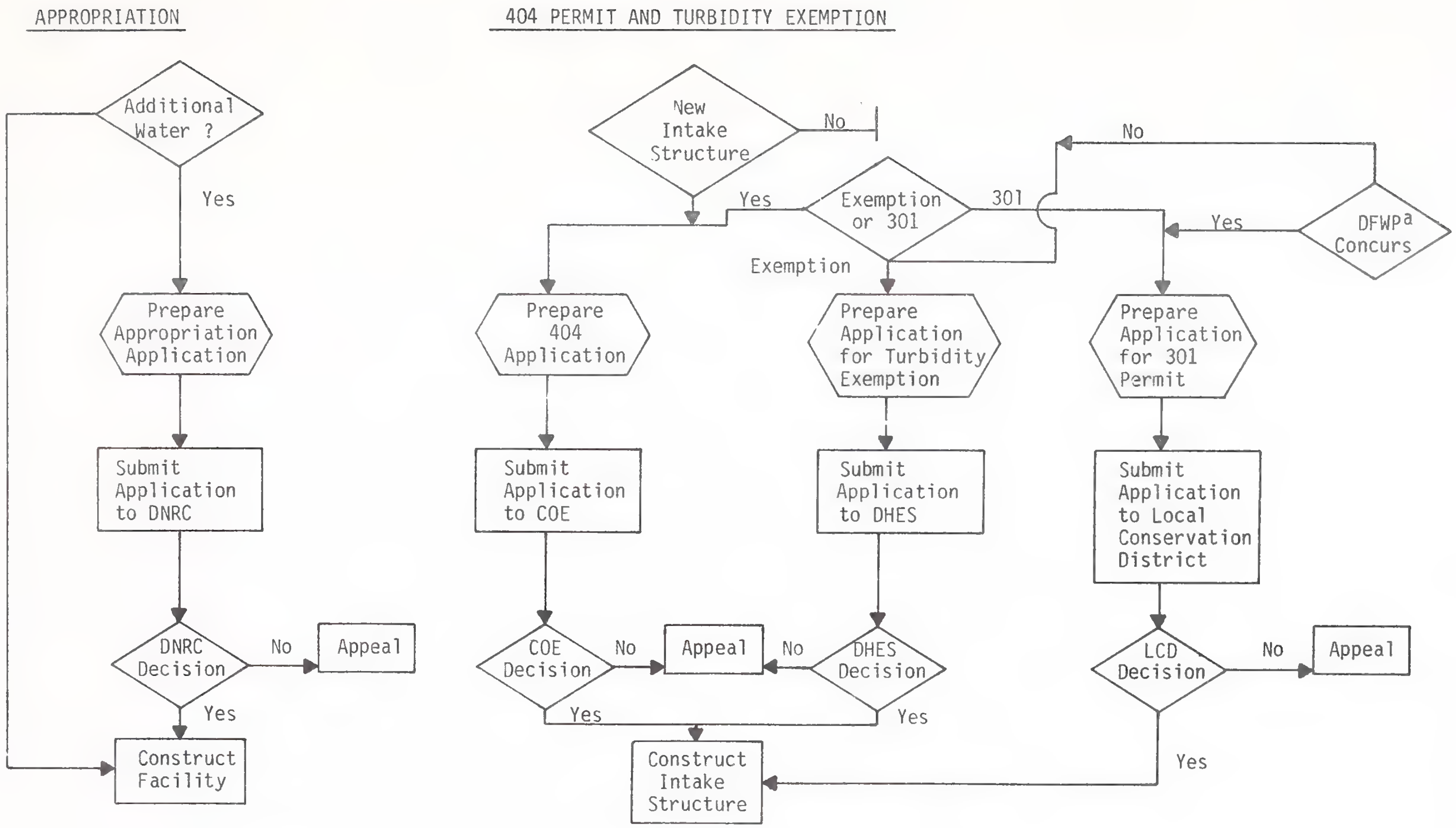
However, this authorization will be required for MHD retrofits of other power plants in Montana if construction activities take place instream. A waiver for this authorization is allowed if the following conditions are met: 1) the applicant obtains a 310 permit from the Local Conservation District (see Section 3.5.1 of this report); and 2) the Montana Department of Fish, Wildlife, and Parks concurs with the waiver. The exemption process is summarized in Figure 3-5.

3.3.2 Federal Regulations

A 404 Permit, obtained from the U.S. Army Corps of Engineers, is required for a project if dredge and fill activities occur either in a stream with a flow greater then 5 cfs or in a wetland. In the case of the retrofit of the Corette plant, a 404 Permit will probably not be required. The current engineering plans indicate the water for the MHD facility will be obtained without building an additional intake structure (the major potential activity requiring dredge and fill).

For other MHD retrofit projects, either within Montana or nationally, the construction of an additional intake structure would be the major activity requiring a 404 permit. Figure 3-5 also summarizes the 404 permit process.

In Montana, and other states with EPA approved water quality control programs, the recognized state agency is responsible for administering the National Pollution Discharge Elimination System (NPDES), the Section 401 Permit (certification), and the New Source Performance Standards (NSPS) for


APPROPRIATION
Additional Water ?
Yes
Prepare Appropriation Application
Submit Application to DNRC
DNRC Decision
No
Appeal
Yes
Construct Facility
404 PERMIT AND TURBIDITY EXEMPTION
New Intake Structure
No
Yes
Exemption or 301
301
Exemption
DFWPa Concurs
No
Yes
Prepare 404 Application
Prepare Application for Turbidity Exemption
Prepare Application for 301 Permit
Submit Application to COE
Submit Application to DHES
Submit Application to Local Conservation District
COE Decision
No
Appeal
No
DHES Decision
Yes
Yes
LCD Decision
No
Appeal
Yes
Construct Intake Structure

[a] DFWP = Department [illegible]

F[illegible] 404 Pe[illegible] [illegible]rbidity Exemptions, And Water [illegible] Regulations in Montana Applicable To An MHD Retrofit

water. These permits, certifications, and standards would apply to an MHD retrofit of an existing plant as previously described. In states without EPA approved programs the State EPA office administers these permits.

3.4 Solid Waste

Solid wastes (such as slag, ash, and spent seed) from an MHD retrofit must be disposed in a manner which complies with all applicable regulations. Solid wastes are classified as hazardous or non-hazardous based on characteristics of the waste. Each type is regulated by separate regulations at the state and national level. Section 2.4.4 of this report describes the proposed waste handling systems for the Corette retrofit.

3.4.1 Montana Regulations

Application of the Montana Solid Waste Management Act 74-10-201 et. seq. M.C.A. to an MHD retrofit of an existing power plant in Montana is not dependent on ownership (federal or private) of the retrofit hardware. Application of solid waste disposal regulations in Montana is summarized in Figure 3-6.

Montana has obtained EPA Phase I approval of its hazardous waste management program. This approval gives Montana, administered by the Department of Health and Environmental Sciences, the primary authority to regulate generators and transporters of hazardous waste. Phase II approval, expected by the end of 1983, will give Montana the primary authority to regulate hazardous waste treatment, storage, and disposal facilities.

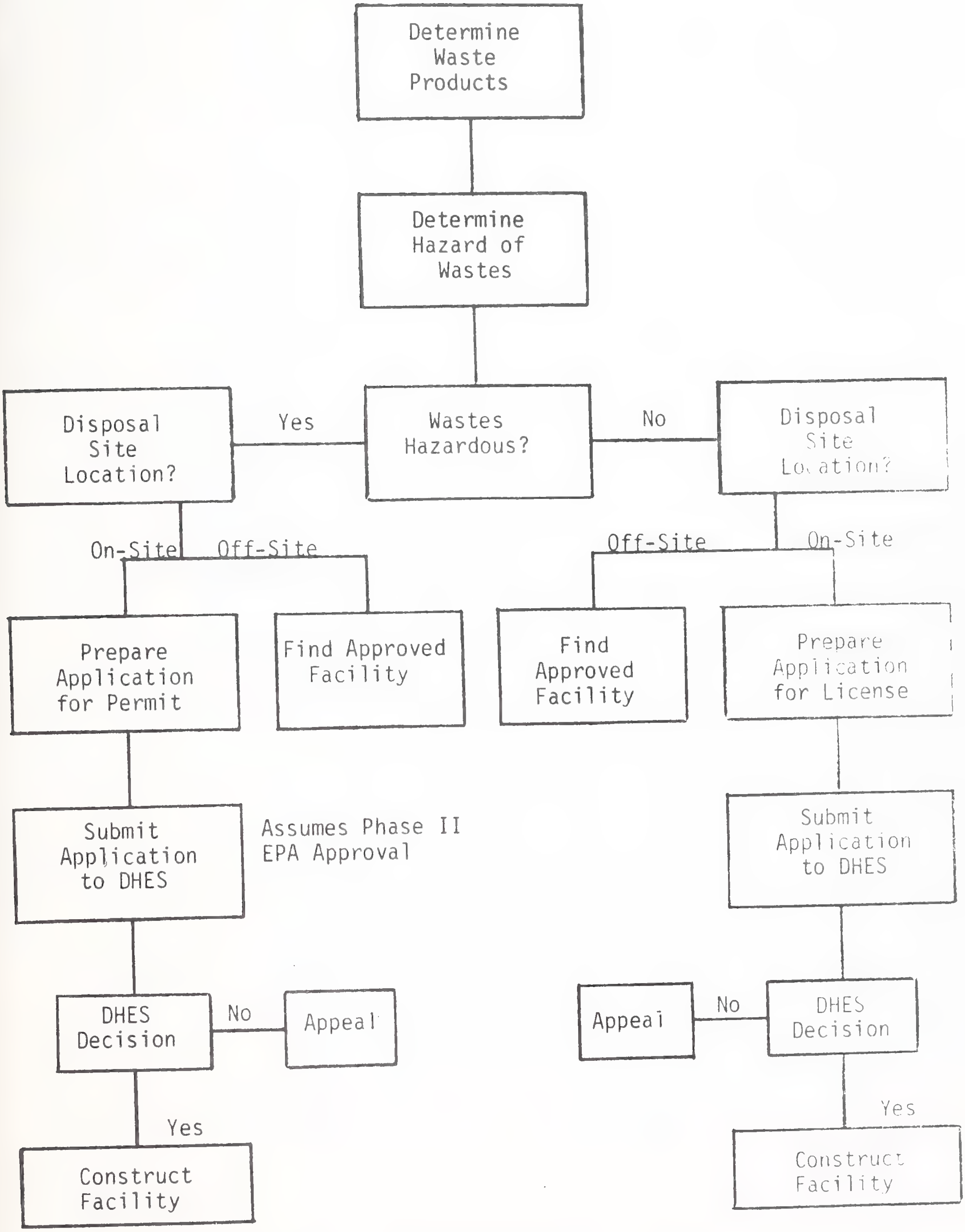


Figure 3-6 -- Application of Solid Waste Disposal Regulations to an MHD Retrofit of Power Plants in Montana

Some wastes, such as fly ash, bottom ash, slag, and flue gas wastes, from conventional power plants are specifically listed as nonhazardous and are exempt from the regulations. However, due to the status of MHD as a new technology, wastes produced from an MHD plant would probably have to be tested for hazardous or nonhazardous classification. The Montana (and EPA) regulations require testing of solid wastes not specifically exempted for their ignitability, flammability, reactivity, and Extractional Procedures Toxicity according to named procedures. The test results would be reported to DHES for confirmation. A recent article in Environmental Science and Technology (Dahlberg 1983) reports that bottom ash slags and fly ash slags from an MHD test facility were found to be non-toxic using the Extractional Procedure Toxicity method. Dahlberg (1983) concluded the bottom ash slags and fly ash slags from the test facility were nonhazardous. However, further testing of all MHD produced solid wastes would probably be required before the Montana DHES or EPA would make a ruling on the hazardous nature of the waste.

If any MHD wastes are found to be hazardous according to the tests or are specifically listed as hazardous they would be regulated by DHES. Generators of hazardous wastes receive an ID number from the regulatory authority and are required to file information as to the nature, volume, and disposition of the waste. Recordkeeping, container labeling, and manifest systems for transport are also the responsibility of the hazardous waste generator.

If the MHD retrofit owner (private or federal) wishes to treat, store, or dispose of hazardous wastes produced by the plant on site, then a permit from

DHES (after Phase II approval by EPA) would be required. Information required for the permit application includes:

- Name and business address of applicant;
- Location of proposed facility;
- The operation and maintenance plans;
- The types of wastes to be handled; and
- A description of pertinent site characteristics.

Both those solid wastes determined to be nonhazardous by testing, and those listed as nonhazardous are also regulated. Disposal of nonhazardous solid wastes requires a license from DHES. The owner of the MHD retrofit would have to submit an application for a license if nonhazardous wastes will be disposed of on-site. Application information includes:

- Applicants name and address;
- Legal and general description of the facility;
- Total acreage of site;
- Pertinent water quality information;
- Geological and soil information;
- Present land use;
- Zoning of site; and
- Proposed operating and maintenance plan.

If the MHD retrofit owner decides to dispose of nonhazardous material off-site then a facility licensed to handle the wastes will need to be

arranged or developed. Yellowstone County operates a Class II landfill which could legally handle nonhazardous MHD wastes from a retrofit of the Corette Plant; however, they could refuse to handle the wastes if the volume was excessive. Discussion with Yellowstone County officials should be initiated early in the final design phase to whether the amount of waste they would accept equates with the amount expected from the plant.

3.4.2 Federal Regulations

In those states where there is an EPA approved hazardous waste management program the process for controlling hazardous wastes is similar to that found in Montana. If wastes from MHD were found to be hazardous then disposal of MHD retrofit wastes in these states would follow the process shown in Figure 3-6. In those states without EPA approved solid waste programs all solid waste disposal (both hazardous and nonhazardous) is regulated by the EPA. The process in this case is similar to that shown in Figure 3-6 except that all applications for licenses or permits are submitted to EPA rather than a State agency. As the State programs were patterned after EPA regulations the EPA requirements are similar to those described for Montana.

3.5 Other Applicable Requirements

3.5.1 Local Regulations

Local (i.e. city and county) ordinances applicable to an MHD retrofit of an existing plant in Montana will vary from place to place; the following

discussion is valid only for the retrofit of the Corette plant in Billings, Montana. The following are regulated by local Yellowstone County ordinances.

- Air Quality;
- Waste Disposal - both solid and sewer;
- Alterations of streambeds or streambanks (310 Permit from Conservation District); and
- Flood Plain Development.

The Air Quality Control Board in Yellowstone County administers the local air quality control program. This program specifically exempts facilities that are regulated by the Prevention of Significant Deterioration (PSD) Rules administered by the Montana Department of Health and Environmental Sciences (DHES). The operation of the Corette retrofit would be regulated by the PSD rules (described in Section 3.2) and so would be exempt from local regulation.

Solid waste disposal in Yellowstone County and Billings is accomplished by dumping in a Class II landfill. This landfill could accept nonhazardous wastes from the MHD retrofit. However, if the volume of the waste is too great the landfill operator can refuse the material. Prior to final design of the plant solid waste disposal methods should be established. No local permits are required for on-site disposal of nonhazardous wastes but the local sanitarian must sign the state permit. (see Section 3.4.1).

Prior to installation of the septic tank system a permit must be obtained from the local government. Before approval is granted the applicant

must perform percolation tests and provide other supportive documentation as required. As the existing Corette plant uses a septic tank system, there should be no problems in obtaining the necessary permit.

The Local Conservation District (LCD) regulates alterations of streambeds or streambanks through the 310 Permit. An entity wishing to construct a project that would require an alteration to a streambed or streambank must apply for a 310 Permit from the LCD. However, since the Corette retrofit project will not need a new intake structure or discharge structure, this permit will probably not be needed.

Since the Corette plant is located on the floodplain of the Yellowstone River, the local floodplain regulations adopted by Yellowstone Board of County Commissioners would apply to an MHD retrofit of the Corette plant. These floodplain regulations require that the entity wishing to construct a structure within a 100 year floodplain submit an application to the Floodplain Administrator for a Floodplain Permit. This application must show:

- Name and Address of Applicant;
- Type of Structure to be built; and
- Location of Structure.

If the application shows that all standards for construction in a floodplain have been met then the administrator will grant the permit. The MHD retrofit

of the Corette plant will meet these standards; no problems should be encountered in obtaining these permits.

3.5.2 State Regulations

If a county in which an MHD retrofit is planned does not have a state approved County Floodplain Program, and, if the retrofit will take place on a 100 year floodplain, then the entity wishing to construct the facility must submit a floodplain application to the Montana Department of Natural Resources and Conservation (DNRC), Floodplain Management Section. Application procedures and construction standards are similar to those described for Yellowstone County.

Additional state environmental regulations applicable to an MHD retrofit of an existing power plant not already discussed were not identified.

3.5.3 Federal Regulations

Other federal environmental regulations applicable to MHD retrofits, in Montana and nationally, include:

- o Fish and Wildlife Coordination Act, 16 U.S.C. 661, _et. seq._ This act requires federal agencies to coordinate their impact analysis of projects with the U.S. Fish and Wildlife Service under certain circumstances;
- o Executive Order 11988, Floodplain Management, May 24, 1977. This order addresses developments on floodplains; and

- Executive Order 11990, Protection of Wetlands, May 24, 1977. This order addresses developments in wetlands.

If the MHD retrofit will be federally owned then some additional federal rules will apply:

- Executive Order 12088, Federal Compliance with Pollution Control Standards, October 13, 1978;
- OMB Circular A-106, Reporting Requirements in Connection with the Prevention, Control, and Abatement of Environmental Pollution at Existing Federal Facilities, December 31, 1974;
- EPA, Procedures for Reporting Proposed Pollution Abatement Projects for Federal Facilities, January 9, 1975;
- DOE Order 5480.1A Environmental Protection, Safety and Health Protection Program for DOE Operations, August 13, 1981;
- DOE Order 5482.1 Environmental Safety, and Health Appraisal Program, June 21, 1979;
- DOE Order 5484.1 Environmental Protection, Safety, and Health Protection Information Reporting Requirements, February 24, 1981; and
- DOE Order 5484.2, Unusual Occurrence Reporting System, August 13, 1981.

3.6 Health and Safety

The Occupational Safety and Health Act (29 U.S.C. 688 et. seq.) established workplace practices to protect the health and safety of workers. Enforcement

is by Occupational Safety and Health Administration (OSHA) inspections of workplaces and issuance of compliance orders, rather than by permit system.

State and Federal Government agencies are not subject to the inspection and enforcement provisions of the Act. Federal agencies are responsible for worker safety and therefore are required to develop employee health and safety programs and must comply with OSHA standards. If the MHD retrofit facility is a government project then the inspection and enforcement provisions of the Act do not apply. However, DOE would be responsible for ensuring that all applicable OSHA standards are met. If the project is privately owned, then all OSHA regulations would apply, including inspection and enforcement responsibilities.

3.6.1 Construction

Worker health and safety during construction would be covered by the OSHA Construction Standards. These standards are common in the construction industry. An MHD retrofit would not present any new hazards during the construction phase.

3.6.2 Operation

OSHA regulations applicable to steam generation facilities will probably apply to the thermal and coal-handling plant. These OSHA regulations establish workplace exposure limits and guidelines for non-ionizing radiation, hazardous materials (including compressed gases and flammable liquids), and toxic and hazardous emissions (including arsenic, benzene, and

several other organic compounds which may result from coal combustion). Also regulated are noise and fire hazards.

The exact nature of all workplace hazards for MHD is not yet known. As the development of an industrial health and safety program for MHD technology progresses, applicable standards will be established. Major new areas of concern for MHD plants include:

- Hazards associated with superconducting magnets;
- Hazards associated with finely ground coal; and
- The oxygen plant.

The oxygen plant associated with an MHD retrofit has hazards not found in the usual steam generator plant. However, OSHA standards have been set that are applicable to operation of an oxygen plant and the MHD retrofit oxygen plant will have to meet these standards.

3.7 Summary of Environmental Requirements

Environmental requirements that are unique to the MHD retrofit of the Corette plant in Billings, Montana are summarized in subsequent paragraphs.

3.7.1 Siting Requirements/NEPA-MEPA

If DOE owns the retrofit, the substantive requirements of the Montana Major Facilities Siting Act will have to be addressed. If the retrofit is privately owned, the substantive and procedural requirements of the Act will have to be addressed.

3.7.2 Air Quality

The design of the retrofit must ensure that New Source Performance Standards (NSPS) for all air emissions will be met. In addition, if Billings is given non-attainment status for SO_2 then the retrofit must control all SO_2 emissions.

3.7.3 Water Quality

Water requirements and waste water disposal will be constrained by environmental regulations. If the retrofit plus the Corette plant will use more than 92,800 acre feet per year or more than 57,550 gallons per minute (the current MPC appropriation for the Corette plant) then an additional appropriation of water will be needed. The current appropriation is for once-through cooling and screen cleaning; thus, it is a non-consumptive use. The MHD retrofit use of this water will also have to be non-consumptive.

Water discharge to the Yellowstone from the retrofit will require an MPDES permit. Current limitations on Corette cooling water discharge indicate that the MHD retrofit will probably not be allowed to discharge waters that would cause an increase in the existing allowable total thermal load from the Corette and Bird plants. This limitation must be taken into account during the final design stage.

3.7.4 Solid Waste

Major considerations that will need to be addressed during final design of the retrofit include solid waste disposal regulations. First, all wastes will need to be identified as hazardous or nonhazardous. Hazardous wastes (if any) will have to be disposed in an EPA or DHES approved manner. Nonhazardous wastes will also have to be disposed in a manner approved by DHES. As no room exists on site for disposal of solid wastes from the MHD retrofit off-site facilities will have to be found. As the county Class II landfill could refuse to handle the nonhazardous wastes a plan for disposal of 4.5 tons/hr of slag, and 5 tons/hr spent seed produced during operation will have be be finalized.

3.7.5 Safety and Health

Safety and Health aspects of the coal handling, oxygen plant, and magnet should be addressed during the final design stage to ensure worker protection. These aspects may be somewhat different than those found for a conventional coal-fired power plant.

3.7.6 Montana Department of Natural Resources and Conservation Response

Montana's Department of Natural Resources and Conservation reviewed the Environmental Requirements Section of this Report. Their comments are found in Appendix B.

4.0 SOCIOECONOMIC CONSIDERATIONS

Retrofit of an existing power plant with an MHD topping cycle will require that applicable socioeconomic regulations and their appropriate socioeconomic requirements be followed. Depending on local and state regulations and the ownership of the MHD system (federal or private) certain siting, historical, archaeological and zoning regulations will have to be met. As discussed in Section 3.0, Environmental Requirements, this Section will also consider three MHD retrofit scenarios:

- MHD retrofit of the MPC Corette Plant, Billings, Montana; DOE ownership of new hardware;
- MHD retrofit of any coal-fired power plant in Montana; private ownership of new hardware; and
- MHD retrofit of a coal-fired power plant anywhere in the country; private ownership of new hardware.

The Montana Major Facilities Siting Act (MMFSA), The Montana Environmental Policy Act (MEPA), and the National Environmental Policy Act (NEPA) were discussed (with relationship to the three ownership scenarios) in Section 3.1 Site Requirements/NEPA-MEPA and depicted in Figures 3-1 and 3-2. To avoid repetition this section will not discuss MMFSA, MEPA, or NEPA requirements with respect to ownership, but will limit to discussion to specific socioeconomic requirements of the three when they do apply.

4.1 MMFSA, MEPA, NEPA

As previously discussed in Section 3.1.1, the MMFSA will apply to a private and/or federally owned retrofit of the Corette Plant in Billings or to any other MHD retrofit in Montana. Socioeconomic considerations required by an applicant for the MMFSA include:

- Developing an inventory of public service facilities and determining their adequacy based on generalized standards of acceptable service. Examples of facilities include water supply, waste water treatment, housing, educational/recreational facilities, health care, police, and fire protection, etc.
- Determine the economic impact on the area based upon the magnitude and speed of population change and the ability of the area to accommodate those changes. Good information on the construction crew and scheduling is necessary to determine the impacts. Once the population changes have been estimated the increases in housing and public facilities can be evaluated and thus a quantitative evaluation can be made.
- Develop a social baseline or community profile based on population profile and utilization and capacity of social services including health and welfare.
- Perform an attitudinal survey of randomly selected people in the impacted area. The survey should address people's attitudes and perceptions about growth, community services, and the proposed development.

- In addition to the community survey, key agencies and organizations affected by the proposed facility should be contacted.
- Describe the visual impacts on the regional topography and physical background characteristics of the site.

NEPA and MEPA applicability was discussed in Section 3.1.1 and 3.1.2 with respect to facility ownership and general Environmental Impact Statements (EIS)/Environmental Assessment (EA) requirements. These two laws are virtually identical in their statements of policy and directions to administrative agencies. State and federal EIS procedures are similar in overall approach although they differ in detail. Federal regulations vary from agency to agency. All state agencies with EIS responsibilities have adopted uniform regulations. With respect to the broad guidelines the applicable socioeconomic factors that must be considered in the draft EIS include immediate and cumulative impacts on the human population in the area to be affected by the proposed action including where appropriate:

- Social structures and mores.
- Cultural uniqueness and diversity.
- Access to quality recreational and wilderness activities.
- Local and state tax base and tax revenues.
- Agricultural and industrial production.
- Human health.
- Quantity and distribution of community and personal income.
- Transportation networks and traffic flows.
- Quantity and distribution of employment.

- Distribution and density of population and housing.
- Demands for government services.
- Industrial and commercial activity.
- Locally adopted environmental plans and goals.

The discussion should take into consideration different scenarios and how they will impact the specific areas including:

- Status quo.
- Proposed development.
- Cumulative impact with more than one development.

4.2 Montana Antiquities Act Permit

4.2.1 Federal Ownership

For any project occurring on federally-controlled lands or which requires federal permits (beyond those related to air and water quality), compliance with the provisions of 36 CFR 800 will be necessary. There is no formal connection between the federal statute (i.e., the National Historic Preservation Act, PL.89-665) and the State Antiquities Act (i.e., 22-3-401 through 442, MCA). As the project will occur on privately-owned (MPC) land, and as the 36 CFR 800 procedures will be triggered only if particular federal permits are required, compliance with the Montana statute is not strictly applicable to the Corette MHD retrofit project. However, as the MMFSA does refer to consideration of cultural resources during the siting process, the spirit of the Antiquities Act should be addressed. This recommendation is discussed in the following subsection.

4.2.2 Private Ownership

The Montana Antiquities Act is triggered solely by projects that will use or disturb Montana state-owned lands. However, it is likely that administrative regulations pertaining to consideration of cultural resources, under the authority of the MMFSA, will be promulgated within a year from now. Such regulations will be similar in content to those found in 36 CFR 800. (Ms. Marcella Sherfy, phone conversation, April 28, 1983.)

The requirements for the determination of cultural resources in the MMFSA are very general. Therefore, the Montana DNRC has followed the federal regulations (36 CFR 800 *et seq.*). The major requirements for the applicant include:

- Evaluation of the historic value of the existing facility.
- Provide information on the land to be disturbed to determine if an inventory will be needed.

4.2.3 Situations Involving Montana State-Owned Lands

The MHD retrofit scenarios include the case of "any coal-fired power plant in Montana" (p. 4-1). In such a general use, the possibility of disturbance of state-owned lands exist. In such an instance, the State Historic Preservation Office (SHPO) personnel would administer the requirements of the Montana Antiquities Act. The applicable requirements include:

- Legal location of project;

- File search to identify previously located historic and archaeological resources;
- Written documentation that SHPO has been contacted and provided with known archaeological or historical sites and information on the likelihood of discovering cultural resources within a project area;
- Provide to SHPO a recommendation on whether an intensive cultural survey is needed;
- If a survey is needed, the applicant must supply a written report including maps, photographs, summary evaluation;
- Mitigation plans or avoidance options for register eligible or state heritage properties; and
- If a federal project, documentation of contact with the Advisory Council on Historic Preservation is required.

There is no statutory timeframe for review and approval or denial of this permit, however once granted, the permit is valid for the lifetime of the project.

4.3 Land Use and Zoning Requirements

4.3.1 Private Ownership

If the facility is located within the limits of a municipality it will be subject to zoning regulations. County zoning in unincorporated areas also exist in some places and where it does not, special zoning districts have been established in many locations.

If subject to zoning regulations, the applicant must submit an application for a building permit for the specific site of construction. The city, county, or city-county planning office will then make a determination whether the application is valid and issue or deny a permit. If the permit is denied, the applicant may request an exception be made to the zoning regulations. Again, the permit may be granted or denied by the zoning board. All decisions may be appealed to the district court within 30 days. With respect to the Corette Plant in Billings, it appears that the facility and retrofit is within an area zoned industrial, therefore the permit should be easily obtained.

4.3.2 Federal Ownership

Zoning regulations do not apply to facilities under the exclusive jurisdiction of an agency of the federal government. However, it may be beneficial to the federal government to voluntarily comply with the zoning regulations.

5.0 COST ESTIMATE

The Engineering Assessment cost estimate prepared for the 250 MW_t MHD Advanced Test System to the Corette power plant represents only capital construction costs.

The costs were organized in a manner similar to the Federal Energy Regulatory Commission (FERC) account structure with separate break out on some systems to parallel the major topics covered in the Engineering Assessment. A definition outlining content and methodology is provided for major categories.

The costs of equipment and materials were based on vendor budgetary quotes, catalogs, past installation costs, Richardson process plant construction estimating standards and other applicable data. Costs are based on 1983 dollars. Total costs were compared with previous MHD studies although no direct costs were extrapolated from those studies. The uncertainties and degree of confidence associated with these costs is also addressed.

5.1 Supportive Definitions

Various definitions were used in developing and categorizing the cost information data. Following is a definition of the terms used.

"Major Equipment" are items described as engineered, designed, fabricated and shipped by a supplier. In some instances a particular supplier will also provide erection services and in other cases foundations only are supplied.

"Balance of Plant" equipment and labor costs are costs for materials and installation labor that are supportive of the Major Equipment. In many cases these items are engineered, designed and/or purchased by the Architectural/Engineering (A/E) firm. These items may be installed under a general construction contract and could be such items as local electrical and instrumentation systems, piping subsystems, communications, small foundations, etc.

"Installation Labor" is the field installation labor that is directly attributable to the item being costed. It includes the average base wage rate and fringe benefit (health and welfare, pension, vacation, education or apprenticeship). In some instances a composite crew average is used.

"Indirect Costs" are based on percentage of the material and labor costs. These costs are defined as all costs that must be added to the direct material, labor, and subcontract costs in order to arrive at an estimate of the total project cost, excluding profit, engineering and contingency.

These indirect costs generally include the job site overhead covering construction equipment, organizational structure, supplies, building layout, expendable tools, etc., and the home office overhead covering principal salaries, office, furniture, utilities, supplies, sales and general equipment.

"Subcontract" costs are total material and labor costs that include indirect costs to complete a particular installed item of work. A percentage is added to subcontract costs to allow for administration of that work by the A/E firm or general subcontractor.

"Contingency" represents an allowance for items that are beyond the control of the designer and are a specific provision for unforeseeable elements of costs within the currently defined scope of work. Contingency does not include any allowances for change in project scope. A 20% contingency factor was used as an average on the entire project. Some areas of the facility are less defined than others and a higher factor could be used while other areas are well defined with backup vendor data where a lower factor applicable. The 20% figure was used as an overall compromise for simplification. Some of the areas that support the use of a contingency are:

- Weather
- Site working conditions
- Unpredictable field conditions
- Project timing uncertainties
- Timing for integration of subsystems
- Market conditions
- Late deliveries
- Unreliable estimating data
- Underestimated material or labor costs
- Errors or omissions
- Labor productivity
- Overtime
- Short term strikes or walkouts
- Instability of labor market
- Design changes but not major project scope changes
- Minor project definition changes
- Other unforeseeable conditions.

"A/E Engineering" is the professional engineering services that will include conceptual design, preliminary (definitive) design, detail design and engineering, architectural design, construction management, shop inspection, procurement, expediting, etc. A 10% figure is used for these services and is generally allocated as follows; 1% for conceptual design, 2% for preliminary design, 4% for detailed design, and 3% for construction management.

"Other Costs" is a category included to cover such items as the utility's field staff and other professional services such as site surveying, building permits, concrete testing, etc. A 1.5% figure is used for those other costs. No allowance was included for governmental participation.

"Environmental Engineering" was included as costs associated with the various permitting activities, including design review requirements which are considered an integral part of overall facility costs.

In addition, the estimate excludes the following items:

- Escalation and allowance for funds during construction (AFDC)
- Developmental costs for critical components or equipment
- Research and simulation equipment
- Land costs and land rights costs; excluding easements for utilities and access road extensions
- Royalties or legal costs
- All federal, state, or local taxes; including ad valorem
- Environmental permits and fees
- Working capital, interest, and financing
- DOE/DNRC expenses connected with this specific work effort; including field staff

- Premium time construction
- Hard rock excavation
- Spare parts including the recommended spare channel
- Furniture and/or mobile equipment necessary
- Cost of telephone service extension from existing telephone facilities to a termination point within the various new buildings
- Cost of leasing temporary office trailers and space for construction management personnel
- Cost of contractor's utilities
- Insurance coverage
- Seed reprocessing facility
- Operation
- Consumable operating material
- Maintenance
- Operator training
- System operating tests
- Total plant checkout

5.2 Cost Estimates

The categories of cost estimates generally follow the FERC account structure and those individual accounts include items or broad categorical areas as defined in the following paragraphs. A summary construction cost estimate sheet showing costs of $187,328,000 is provided at the end of this section. Cost work sheets are in Appendix D.

Structures and Improvements: Includes top soil removal and replacement, relocation of existing structures, yard drain line, oil pump discharge line, bottom ash line, and other miscellaneous items requiring removal or

relocation to prepare the site for construction. A construction rail spur is included as well as all buildings, their foundations, and floor slabs. Building bridge cranes and an elevator are included as well as some allowance for unit heaters. Equipment for the on site liquid waste treatment is also included as a portion of the waste treatment building.

Coal Preparation: This account was separated out from the normal boiler plant account and includes the interface with the existing coal reclaim system, conveyors, coal bunkers, coal preparation, and the lock hopper injection system. Vendor budget quotations were obtained for the primary coal preparation equipment and include only one coal pulverizer but allows for a foundation for the second coal pulverizer.

Heat Recovery/Seed Recovery: This section includes the boiler and all accessory items necessary for envelope operation of the HRSR. The unique design and construction requirements generally dictate that a major manufacturing supplier be subcontracted for installation of the entire unit on foundations already in place. Babcock and Wilcox provided costing data on units that had been previously budgetary costed. These figures were then adjusted for inflation and a size ratio applied to conform to the Advanced Test System (ATS) requirements.

Particulate Control Device: This section was separated out from the boiler plant account as it is a major equipment item with specific design and construction requirements. The cost of the particulate control device was obtained from supplier data which was updated with an inflation factor and then adjusted with a sizing ratio. The stack was also included in this account.

Steam Piping: This account includes the superheat, cold reheat, and hot reheat steam piping. Some allowance was also included for some low pressure steam piping and condensate return systems.

Accessory Electrical and Control: This account includes the miscellaneous wiring and protective switchgear that is required for electrical service to various motors. The auxiliary transformers are included in the substation and transmission account. Motors are included along with the appropriate equipment in the other accounts. The Distributed Digital System (DDS) for control purposes and the data acquisition system as well as field instrumentation is included in this account. Westinghouse and Foxboro provided budgetary information on the DDS.

Plant Support Equipment: Included in the account are such items as cooling water heat exchangers, miscellaneous circulating pumps, mixed bed demineralizer, service and instrument air compressor, condensate tank, booster boiler feedwater pump, potable water system, building and perimeter fire system, inverter cooling tower, natural gas supply, and miscellaneous maintenance equipment.

MHD Power Train: This account includes the coal-fired combustor, MHD channel, diffuser, and their closely related systems. Previous budgetary pricing was obtained from past studies and compared to available information from Avco Everett Research Laboratory costs which had been adjusted for inflation.

Superconducting Magnet: The SCM was accounted for separately and included the helium refrigeration system. Budgetary pricing was obtained from the Plasma Fusion Center, Massachusetts Institute of Technology on the system as a whole.

Inverter: The inverter was also separated out of the MHD account to provide a separate more meaningful figure. Prices were obtained independently on the inverter using current information from the recently completed system at the Component Development and Integration Facility (CDIF), Butte, Montana.

Seed System: This system was estimated separately from the MHD account as it is a relatively minor account but distinctly apart from the MHD channel. The system includes the unloading, silo storage, reclaim, weighing, and injection of seed.

Air Separation and Compressors: As a major component of the ATS facility, the air separation unit was budgetary priced by Air Products and Chemicals, Inc. and Lotepro Corporation. The prices included the major compressors and motor drives and were for battery limit turn-key installations.

Substation and Transmission: This account includes the substation equipment and transmission line. All transformers, switchgear, safety devices, towers, and associated equipment is included in this account.

5.3 Confidence Level

The confidence level in the total project cost is expected to be -10% to +30% of the 187.3 million dollars estimated capital construction costs. This confidence level was determined primarily by the uncertainty of the high technology items such as the MHD power train and the Heat Recovery Seed Recovery unit. There is a fair level of confidence on the systems that are currently available in the market place although complete system definition of the Advanced Test System (ATS) is not established. There is still some uncertainty in portions of the piping subsystems, control systems, liquid and solid waste disposal and other areas where this preliminary engineering assessment was not sufficient to provide adequate detail for firm costing figures.

Taking the 30% confidence level into consideration the capital construction cost could be as high as 243.5 million dollars. The capital construction cost estimate compares favorably with other studies which have been made on similar size MHD facilities.

TABLE 5-1

ESTIMATED CONSTRUCTION COSTS FOR OXYGEN ENRICHED 250 MW_t MHD RETROFIT TO CORETTE POWER PLANT

COST SUMMARY SHEET

(Costs are in 1983 dollars expressed in thousands)

Description	Installed Cost	Balance of Plant	Total
Structures & Improvements		$ 6,496	$ 6,496
Coal Preparation	$ 7,560	1,512	9,072
Heat Recovery/Seed Recovery	20,224	4,045	24,269
Particulate Control Device	6,567	657	7,224
Steam Piping	1,459	146	1,605
Accessory Electrical & Control	1,886	377	2,263
Plant Support Equipment	934	187	1,121
MHD Power Train	12,814	2,563	15,377
Superconducting Magnet	31,268	6,254	37,522
Inverter	5,208	1,042	6,250
Seed System	490	98	588
Air Separation & Compressors	21,185	4,237	25,422
Substation & Transmission	1,583	317	1,900
SUBTOTAL			$139,109
A/E Engineering 10%			13,911
Other Costs 1 1/2%			2,087
Environmental Engineering			1,000
SUBTOTAL			$156,107
Contingency 20%			31,221
TOTAL			$187,328

6.0 PROJECT SCHEDULE

An overall MHD Retrofit Project Schedule has been prepared showing summary level activities. From this schedule an MHD retrofit to the Corette Plant can be achieved by 1990, with operation for commercial demonstration being initiated by 1991.

The key assumptions used in establishing this schedule were:

1) Site selection and the necessary host utility negotiations start during the last quarter of 1983.

2) Major MHD components (combustor, channel, magnet, HRSR, ASU, and inverter) are long lead items and procurement of these be initiated as early in the project as possible.

3) The retrofit project is considered a first-of-a-kind and a period of four (4) years has been used for the accomplishment of construction activities.

4) Equipment deliveries and erection are completed during the estimated construction time shown.

The purpose of this schedule is to show only the minimum estimated times to accomplish key functions for project completion. Engineering activities consist of four (4) major areas; conceptual design, preliminary design, detail design, and field support. These activities consist of the following:

Conceptual Design

The purpose of a conceptual design is to develop:

- A project scope that will satisfy program needs to assure project feasibility and performance levels
- Initial cost estimates and schedules
- General project criteria and design parameters
- Applicable codes and standards
- Quality requirements
- Utility services
- Functional space allocations
- Process requirements
- Outline equipment specifications
- Methods of performance
- Safety and health requirements

Preliminary Design

This activity consists of:

- Obtaining topographical and other field surveys
- Test borings and other subsurface investigations
- Establish architectural and engineering criteria for detail design efforts
- Conduct studies and prepare preliminary sketches, drawings, and layouts
- Revise equipment outline specifications
- Preparation of preliminary cost estimates and schedules for completion of design and working drawings, procurement specifications for construction, and identification of potential problems
- Preparation of Piping and Instrument Drawings (P&ID's) for a basis of process detailed design activities

Detailed Design

This activity involves:

- Preparation of working drawings and procurement specifications
- Preparation of construction specification
- Revision of cost estimates and schedules
- Procurement activities including the evaluation of proposals and bids for materials, equipment, and services

Field Support

Field support services include:

- Assuring conformity of construction work to approved design, working drawings, and specifications
- Providing laboratory tests of construction workmanship, materials, and equipment as required
- Providing "as built" record drawings and specifications showing construction as actually accomplished
- Provide liaison between design entity and general contractor

The project organization to accomplish an MHD retrofit to the Corette plant is not addressed. However, a key function of the overall schedule is utility negotiation. This consideration is included in the schedule since the retrofit is anticipated to be a joint effort by the Department of Energy and a consortium of private utilities with the host utility providing a major role in the overall project management.

The necessary development for obtaining the major MHD components is not shown on the overall project schedule. However, this consideration is addressed in Section 7.0, "Program Implementation."

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7.0 PROGRAM IMPLEMENTATION

The national MHD Program Plan has been reviewed and modifications to the national program that reflect the retrofit concept proposed for the Advanced Test System are recommended. The resulting engineering development program, formulated to provide the engineering database required to support the Advanced Test System (ATS) project, is outlined.

Clearly, any number of such development programs can be formulated depending upon the criteria established for specifying acceptable technical, cost, and schedule risks for the overall ATS program.

The development program outlined here is based upon an assumption by program participants of a moderate, acceptable technical risk in order to provide reasonable development costs and schedules.

The recommended development program is essentially a minimum, baseline program. Consequently additional technical milestones can be added to the program, depending upon future cost and schedule constraints, to further reduce uncertainty. However, since the criteria used to generate this development program dictates a moderate, acceptable risk, only minor reductions in the proposed development program could be tolerated before the overall risk to the successful extrapolation from the proposed test program to ATS performance would be judged as relatively high.

A number of alternatives to the recommended baseline program associated with both greater and lesser uncertainty development scenarios are also presented.

The overall program required for development of the ATS is comprised of three principle phases:

I. MHD Engineering Database
II. ATS Model Simulation Experiments
III. ATS Design, Construction, and Test

Phase I & II comprise the baseline engineering development program required to support Phase III, the actual ATS design, construction, and test program.

The two phases of the recommended engineering development program are presented in detail.

I. DEVELOPMENT OF MHD ENGINEERING DATABASE

This phase of the development program consists basically of completing several well conceived, essential database tests presently identified in the national MHD program. The principle outstanding experimental program required to support ATS is an integrated test of a coal-fired combustor and channel at the 50 MW_t thermal power level. As a prerequisite, the performance of the 50 MW_t coal-fired combustor should also be determined independently of the the channel. In the test progression suggested here, the MHD database tests will be conducted at a moderate magnetic interaction (i.e. $B \cong 3.0$ Tesla) utilizing an existing iron-core magnet. Higher magnetic interaction, simulating ATS channel conditions will be obtained in Phase II of this development program.

The proposed database tests will utilize MHD components currently under development in the national program.

The minimum acceptable integrated test, based upon presently planned components in the national program, utilizes a first-generation "COAL-FIRED COMBUSTOR" (CFC) in conjunction with an MHD channel from the federally designated 1A channel series.

In addition to these minimum baseline tests it is desirable from the point of view of reducing risk to include tests of the CFC integrated with an advanced channel, perhaps from the federally designated "1B" channel series modified for supersonic operation, if this channel construction is considered prototypic of the ATS design following further manufacturer research and development.

An even more conservative database development program, in terms of overall risk, provides in addition, test results at the 50 MW_t level for a second-generation COAL-FIRED COMBUSTOR, more representative of anticipated ATS design, integrated with the modified "1B" advanced channel, if applicable.

The MHD power train engineering development tests described here should logically be conducted in the national Component Development and Integration Facility (CDIF) since this facility was originally designed to accommodate the flow requirements of these test components.

In addition to the the MHD power train tests just described, key "HEAT RECOVERY-SEED RECOVERY" (HRSR) tests should be conducted at the $20MW_t$

thermal input power level to complete the engineering database required to support design of the ATS "model" HRSR described in Phase II. Key elements yet to be evaluated in HRSR testing include the addition of superheat and reheat sections. These tests should be conducted at the national COAL-FIRED FLOW FACILITY (CFFF), utilizing existing components.

Concurrently with the above flow-train tests, manufacturers' component research and development programs should be continued at a level necessary to provide the components specified for these performance verification tests.

II. ATS MODEL SIMULATION EXPERIMENTS

The second phase of the ATS development program will utilize "model" test components chosen to accurately simulate the performance characteristics expected in the actual ATS. The results obtained from these model tests will: (1) confirm component designs selected for the ATS; (2) provide the basis for modification where performance of the model tests is not up to expectations; and (3) verify analytical prediction of overall system performance to provide the confidence needed to continue development of the full-size ATS.

As indicated, a principle purpose of these proposed "model" tests is to simulate as closely as feasible the conditions expected in the actual full-size ATS. Obviously, the technical issues and problems associated with designing well-simulated model experiments and ultimately extrapolating these model test results to conditions expected in the full-size ATS become more

tractable as the size of the model experiments increase and approach the size of the full-size ATS.

Consequently, one of the first issues to be resolved in the design of model tests is to establish the scale (size) of the model tests relative to the full-size ATS. Essentially, this has already been accomplished since the upper limit on ATS size was earlier established based upon moderate risk extrapolation from the existing national $50mw_t$ test facilities. These scaling arguments are more fully developed from a different perspective here to emphasize the mutual dependence of model simulation test and ATS scales.

A trade-off is obviously required when selecting the scale of the model tests to simulate the ATS prototype i.e., larger scale model tests clearly reduce the uncertainty in predicting (extrapolating to) full-size ATS performance from model test results while concurrently increasing development costs.

Unanimous agreement does not exist concerning the ideal scale factor (model size to full-size) appropriate to the proposed tests since a consensus has not been developed on the risk that should be assumed by the participants. However, a factor of five in thermal input power is near the limit for obtaining the moderate, acceptable risks proposed in this engineering assessment as the basis for estimating full-size ATS expectations from model test results.

Summarizing, the sizes of the ATS and the supporting model simulation experiments have been shown to be 250mw$_t$ and 50mw$_t$ respectively, based upon the proposed risk criteria. Any future reduction in the proposed size of ATS, which is not recommended because of the possibility of unacceptably increasing the uncertainty in scaling from ATS to commercial sizes, or any future increase in the size of the model simulation experiments would decrease the uncertainty in scaling between model tests and ATS. Conversely, substantial reduction in the scale of the model experiments will significantly decrease the confidence that full-size ATS performance can be estimated from the model results.

The baseline model simulation tests proposed here consist of experimentally determining the performance of an entire integrated MHD flow train comprised of combustor, channel, diffuser, HRSR, superconducting magnet, and inverter -- in effect, a complete small-scale flow train simulating the characteristics of the full-size ATS flow train. A key feature of these tests is the attainment of high magnetic interaction (magnetic field strength of at least 4.5 Tesla) in conjunction with supersonic channel operation. To minimize development costs, steam turbines are not proposed for these experiments since their characteristics are well understood.

The basic MHD test components required for the proposed model simulation tests are similar in concept to the Advanced Power Train (APT) components presently being studied in the national program. These APT components could probably serve as the basis for component development for the proposed model simulation experiments.

Because of the availability of two national MHD test facilities, an alternative model simulation experiment that utilizes both facilities should

be addressed. Such a test program would consist of separate, instead of integrated, tests of the MHD power train (combustor, channel, diffuser, magnet, and inverter) and the Heat Recovery-Seed Recovery (HRSR) unit. HRSR tests would be conducted in the national Coal-Fired Flow Facility (CFFF) at a thermal input power level of 20 MW_t while the MHD power train would be separately tested at the national Component Development and Integration Facility (CDIF) at a thermal input power of 50 MW_t. The principle advantage of this alternative model simulation test program is reduced cost and schedule because of smaller scale HRSR components. However, the increased technical risk associated with confidently predicting performance of a fully integrated, full-size ATS from separate MHD power train and HRSR tests probably exceeds the baseline development program criteria of moderate, acceptable risk established in this engineering assessment. The further increase in scaling uncertainty between a 20 MW_t HRSR and a 250 MW_t full-size ATS also indicates this as a relatively high risk option.

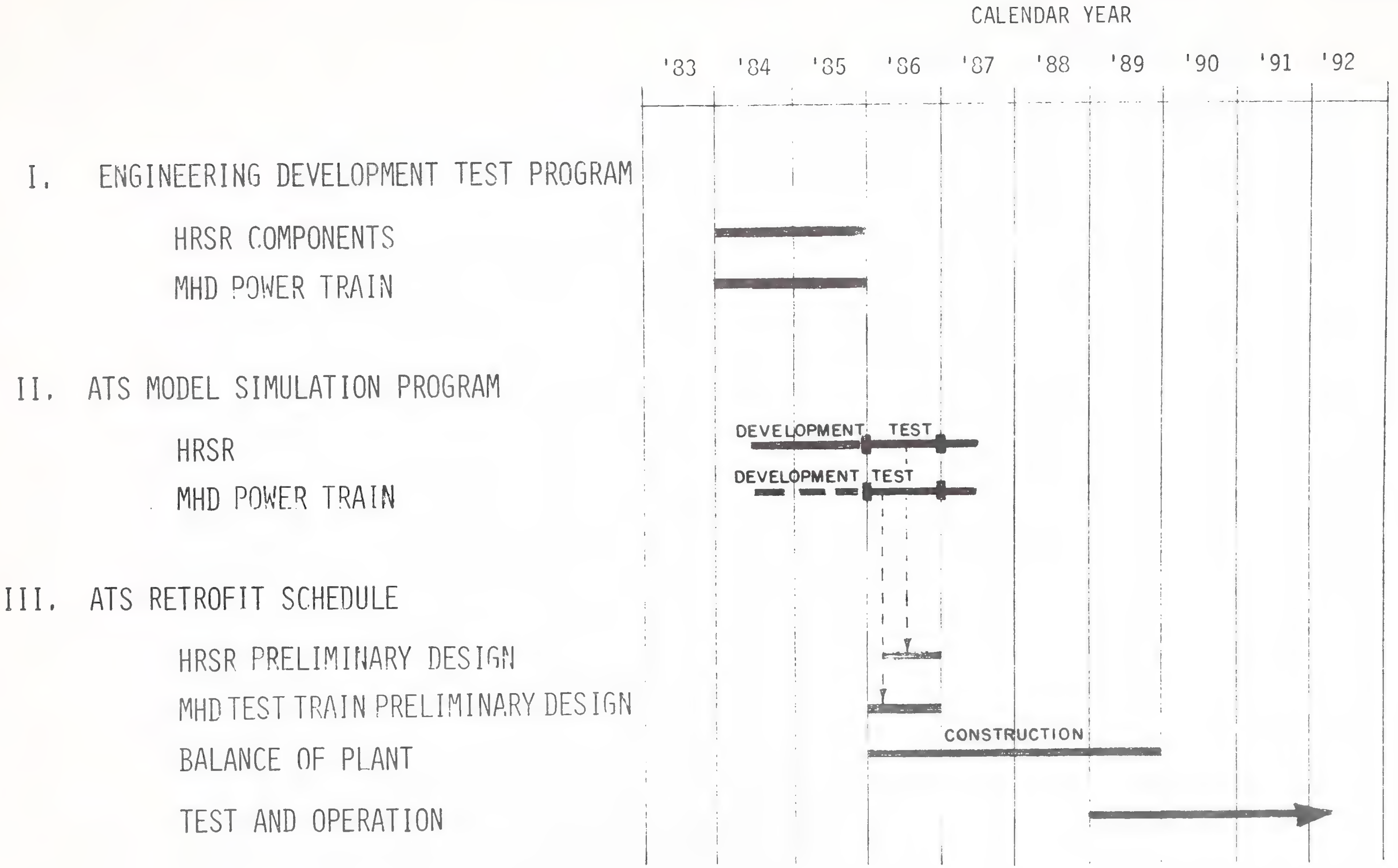
The major elements of the recommended redirection of the national program to support the ATS retrofit program are superimposed in Figure 7-1 on a summary of the ATS schedules developed in previous sections, which are based upon conventional design and construction practices. Detailed schedules to accomplish the engineering development program have not been established, however, key interfaces between the engineering development program and ATS design and construction are shown.

An examination of Figure 7-1 makes it clear that the development program must be expeditiously pursued if these schedules are to be met.

It should be pointed out that, although the development of a seed regeneration process is required for ultimate commercialization of MHD, it is not critical to the operation of the ATS, as pointed out earlier and is consequently not shown on this schedule.

FIGURE 7-1

INTERFACE OF RECOMMENDED NATIONAL PROGRAM WITH ATS RETROFIT



8.0 TOPICS FOR FURTHER STUDY

8.1 Initial Discussion

The scope of work, particularly schedule and cost, of the Engineering Assessment constrained both additional and further in-depth study of several unresolved areas of the Advanced Test System retrofit at the Corette plant. The continuation of engineering work during the conceptual design phase will provide an opportunity for further studies in areas where the design requirements are not completely resolved at this time.

For instance, a coal-fired coal preparation system has been recommended as a state-of-the-art method to reduce the moisture of the Montana Rosebud coal from 25.5% to 5.0%. Evaluation of this system during the conceptual design would further define the system, component selection and layout. Additionally, the tradeoffs in using only nitrogen rather than the above system for coal drying could be evaluated. This evaluation would have to include consideration of: 1) HRSR back-pass mass heat and flow balances; 2) physical sizing and layout of the flue gas to nitrogen heaters; 3) state-of-the-art coal drying equipment selections; 4) cost comparisons; 5) efficiency comparisons; 6) operational requirements during intermittent or steady-state MHD operation: 7) possibility of off-grade moisture coal for MHD power train startups; 8) safety considerations and nitrogen inerting requirements if predried coal is stored for long periods of time; 9) energy requirements if interim drying is necessary; and 10) other design considerations.

8.2 Study Topics

The topics that require further study, as shown below, have been partially defined in this and other studies, but require a greater level of design scrutiny before final incorporation into the ATS. Further design studies would be performed in the conceptual, preliminary, and final (detailed) design phases. The present tabulation is a starting point for those studies. Included are areas specific to MHD component development, and integration and balancing concerns for both plants.

It is well understood that further engineering design phases are required and the subsequent tabulation could assist in identifying areas of study in addition to the normal design considerations. In some areas it should be understood that even the next phase of conceptual design may not provide sufficient detail and that the preliminary or detail design phases may be necessary to resolve the final design.

The study area topics are:

- Supply and balancing of steam from two completely separate boilers to a single turbine-generator;

- Control scheme for the dial feedwater and steam systems, including supervisory computer control functions;

- Imbalance in the turbine-generator and its condenser as a result of disruptive feedwater flows and additional condensate collection;

- Disruptions in the turbine generator condenser from the HRSR turbine bypass system during startup periods;

- Requirement for a new condenser to alleviate load disruptions on the existing turbine-generator during HRSR start-up or MHD power train checkout conditions;

- Mass flow and heat balances resulting from cooling of MHD power train during startup and transient conditions to prevent localized backing, both in the MHD power train and the HRSR;

- Mass and flow balance for service cooling water to provide fuller utilization of both the existing and proposed systems;

- The possibility of using water cooling radiators for the service cooling water system; i.e., bearing cooling water and the possibility of using that heat;

- Utilization of the low-grade thermal heat from the inverter and channel cooling water systems for facility building heating, including the requirement for a small auxiliary heating boiler;

- Potential for use of low-grade thermal heat to heat gaseous nitrogen for coal drying;

- Loss of organic volatiles from coal drying and the environmental consideration of these losses to the atmosphere;
- Evaluation of coal-fired coal drying verses other coal drying systems; i.e., flash drying, steam drying, or nitrogen drying;
- Cost and design analysis of coal interface location;
- Potential interference of No. 5 coal conveyor support structures with building structures;
- Initial installation of one or two coal pulverizers;
- Cost verses performance trade-off studies on optimizations of oxygen enrichment;
- Instrument air requirement with electronic or pneumatic instrumentation;
- Will the area designated for particulate control device be adequate for a bag house;
- Confirm off site disposal or potential sale of solid wastes;
- Evaluate size of existing bottom ash ponds to accept ATS liquid wastes;
- Adequacy of existing plant services and total requirements for potable water, fire protection system, natural gas, and auxiliary heating steam;

- Continued development work on the coal-fired combustor;
- Continued development work on the MHD channel; and
- Continued development work on the HRSR.

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20. "RCRA Leachate Analysis of Slag From Magnetohydrodynamic (MHD) Coal Combustion", Michael D. Dahlberg, Environmental Science and Technology, Vol. 17, No. 3, March 1983.

21. "Federal, State and Local Government Permit Requirements for Resource and Energy Development in the State of Montana", Kay Harrison, Governor's Office, State of Montana, Helena, Montana, November 1982.

ATTACHMENT #2

EEI MHD TASK FORCE STATEMENT

EEI/MHD TASK FORCE

The review of the Phase II report, "CORETTE MHD RETROFIT ENGINEERING ASSESSMENT", was found to be complete and that all elements of the study were addressed. The Phase II study met the Phase I requirements and is approved. Some specific issues requiring further consideration were identified and will be addressed by the individual members of the review committee direct to Mountain States Energy.

Approved by the Task Force
June 2, 1983

Joe [illegible], Chairman

ATTACHMENT #3

INVOICE

Mountain States Energy Inc.
POST OFFICE BOX 3662
BUTTE, MONTANA 59702
(406) 723-8182

INVOICE

Date: June 14, 1983
Contract: DNRC Milestone VIII
Invoice No: DNRC-07

Department of Natural Resources
32 South Ewing Street
Helena, Montana 59620

Direct Labor	$ 7,127.94	
Fringe	2,950.82	$10,078.76
Overhead		3,945.02
Other Direct		
Travel	3,572.00	
Computer Support	111.00	
Contract Services	5,100.00	
Reproduction	460.90	9,243.90
General & Administrative		5,228.51
TOTAL COSTS		$28,496.19
Fee		5,062.50
TOTAL INVOICE		$33,558.69
LESS ADVANCE		25,000.00
BALANCE DUE ON THIS INVOICE		$ 8,558.69

ATTACHMENT #4

ESTIMATE MILESTONE #9

ESTIMATED COSTS

MILESTONE NO. 9

DIRECT LABOR	$13,685	
FRINGE	5,664	$19,349
LABOR OVERHEAD		7,154
OTHER DIRECT COST		
Travel	6,000	
Materials and Supplies	100	
Subcontract	4,300	10,400
Direct Costs		$36,903
GENERAL AND ADMINISTRATIVE		7,917
COST		44,820
FEE		5,062
PRICE		$49,882

ATTACHMENT #5

MILESTONE SCHEDULE AND STATUS REPORT

PAGE 1 OF 1

MILESTONE SCHEDULE AND STATUS REPORT

1. Contract Identification Department of Natural Resources and Conservation

2. Reporting Period through

3. Contract Number

4. Contractor (name, address)
Mountain States Energy, Inc.
P. O. Box 3767
Butte, MT 59702

5. Contract Start Date November 1, 1982

6. Contract Completion Date June 29, 1983

7. Identification Number	8. Reporting Category (e.g., contract line item or work breakdown structure element)	9. 1982			1983						10. Percent Complete	
		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	a) Planned	b) Actual
DNRA	DETERMINATION OF PLANT TO BE USED FOR RETROFIT			▼ ▲								
DNRB	SPECIFICATION OF BASELINE CONFIGURATION				▼ ▲							
DNRC	CONFIGURATION ANALYSIS					▼ ▲						
DNRD	DETERMINE DESIGN REQMTS						▼	▲				
DNRE	REVISION OF DESIGN REQUIREMENTS							▼ ▲				
DNRF	COST AND SCHEDULE ESTIMATES								▼ ▲			
DNRG	IMPACT ON NATIONAL MHD DEVELOPMENT PROGRAM								▼ ▲			
DNRH	DRAFT ENGINEERING ASSESSMENT									▼ ▲		
DNRI	ISSUE ENGINEERING ASSESSMENT									▼		

11. Remarks

12. Signature of Contractor's Project Manager and Date

	IDENT NUMBER	DESCRIPTION	SCHEDULED START	ACTUAL START	SCHEDULED COMPLETION	ACTUAL COMPLETION
1.	DNRA	DETERMINATION OF PLANT TO BE USED FOR RETROFIT SC - INITIATION OF CONTRACT WORK AS AUTHORIZED BY THE DEPT. CC - OBTAIN EEI CONCURRENCE AND SELECTION OF CANDIDATE MONTANA PLANT	11-01-82	11-01-82	12-07-82	12-10-82
2.	DNRB	SPECIFICATION OF BASELINE CONFIGURATION SC - SUCCESSFUL COMPLETION OF MILESTONE 1 AS INDICATED BY DEPARTMENT APPROVAL CC - THE ISSUANCE OF PRELIMINARY BASELINE SPECIFICATION TO BE USED FOR FOLLOW ON WORK	12-01-82	12-13-82	01-06-83	01-07-83
3.	DNRC	CONFIGURATION ANALYSIS SC - SUCCESSFUL COMPLETION OF MILESTONE 2 CC - THE ISSUANCE OF A PLANT CONFIGURATION TO BE USED FOR FOLLOW ON WORK	12-29-82	01-03-83	02-09-83	02-18-83
4.	DNRD	DETERMINE DESIGN REQUIREMENTS SC - SUCCESSFUL COMPLETION OF MILESTONE 3 CC - ISSUANCE OF A DRAFT DESIGN REQUIREMENTS TO TEN UTILITIES FOR CONCURRENCE	01-27-83	01-31-83	03-30-83	04-08-83
5.	DNRE	FINALIZATION OF DESIGN REQUIREMENTS SC - SUCCESSFUL COMPLETION OF MILESTONE 4 CC - OBTAIN UTILITY CONCURRENCE	03-14-83	03-21-83	04-26-83	04-29-83
6.	DNRF	COST AND SCHEDULE ESTIMATES SC - SUCCESSFUL COMPLETION OF MILESTONE 5 CC - ESTIMATED COST OF MHD RETROFIT AND SCHEDULE FOR RETROFIT ACCOMMODATION	04-11-83	04-20-83	05-17-83	05-25-83
7.	DNRG	IMPACT ON NATIONAL MHD DEVELOPMENT PROGRAM SC - COMPLETE MILESTONE 5 OR APPROVED BY THE DEPARTMENT CC - RECOMMENDATION TO THE NATIONAL MHD PROGRAM	04-18-83	04-20-83	05-17-83	05-25-83

KEY MILESTONE LIST

	IDENT NUMBER	DESCRIPTION	SCHEDULED START	ACTUAL START	SCHEDULED COMPLETION	ACTUAL COMPLETION
8.	DNRH	DRAFT ENGINEERING ASSESSMENT SC - COMPLETE MILESTONES 6 & 7 CC - ISSUE DRAFT ENGINEERING ASSESSMENT	05-02-83	05-10-83	06-07-83	06-10-83
9.	DNRI	FINALIZE ENGINEERING ASSESSMENT SC - COMPLETE MILESTONE 8 CC - ISSUE FINAL ENGINEERING ASSESSMENT	05-25-83	06-06-83	06-29-83	